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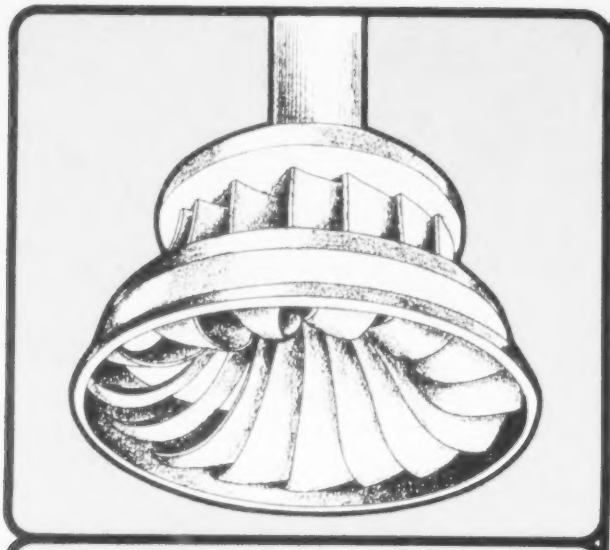

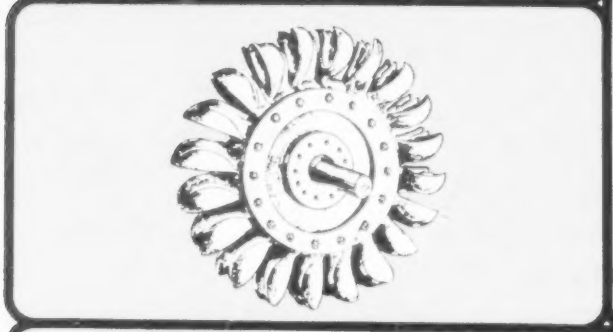

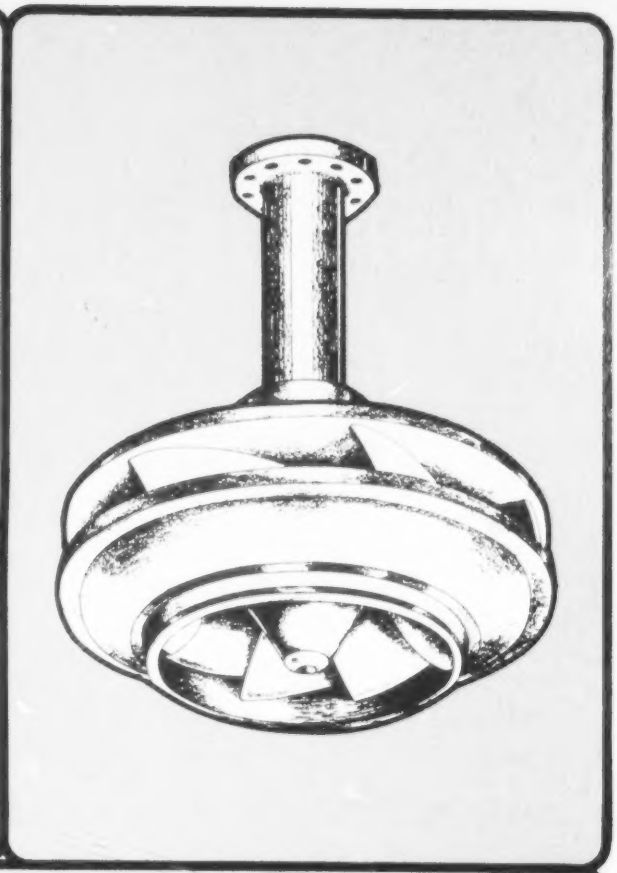

TURBINE PERFORMANCE TEST Unit G24

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Grand Coulee Dam

Grand Coulee Third Powerplant
Columbia Basin Project

Flow Measurement by the Pressure-time Method

Report No. HM-25

UNITED STATES
DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

I27.2:

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. **HM-25**	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE **Turbine Performance Test – Unit G24 Grand Coulee Dam Grand Coulee Third Powerplant Columbia Basin Project**	5. REPORT DATE December 1984 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) **LeRoy Heigel, Allen B. Lewey, and Jan P. Favero**	8. PERFORMING ORGANIZATION REPORT NO. HM-25
9. PERFORMING ORGANIZATION NAME AND ADDRESS Engineering and Research Center Bureau of Reclamation Denver, Colorado 80225	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE DIBR

15. SUPPLEMENTARY NOTES

Microfiche and/or hard copy available at the E&R Center, Colorado

Ed:RNW

16. ABSTRACT

A performance test was conducted June 7 to 9, 1983, on the vertical-shaft, Francis turbine at Grand Coulee Third Powerplant, Grand Coulee Dam, Washington.

Operating characteristics were determined: i.e., horsepower, discharge, efficiency, and flow index calibrations.

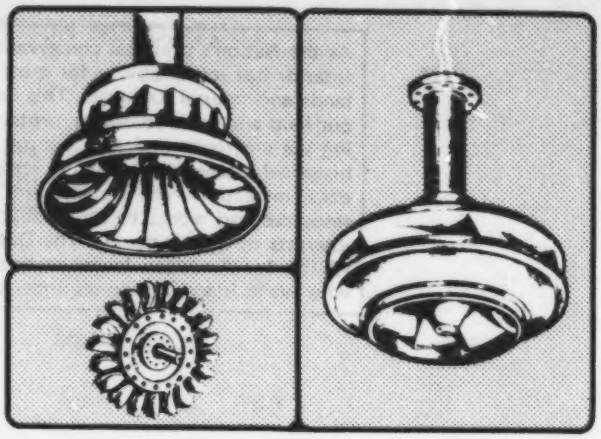
17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- turbogenerators/ Francis turbines/ *Gibson method/ turbine efficiency/ generator/

b. IDENTIFIERS-- Grand Coulee Third Powerplant, Washington

c. COSATI Field/Group 10 COWRR: 1307.1 SRIM:

18. DISTRIBUTION STATEMENT Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161.	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	21. NO. OF PAGES 59
	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. PRICE



TURBINE PERFORMANCE TEST – UNIT G24

GRAND COULEE DAM
GRAND COULEE THIRD POWERPLANT
COLUMBIA BASIN PROJECT

Flow Measurement by the Pressure-time Method

December 1984

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Denver, Colorado

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TURBINE SOLICITATION NO. DS-7001

Vertical-shaft, Francis turbine
rated 960,000 horsepower at
a head of 285.0 feet

First commercial operation	March 1980
Date of Test	June 7 to 9, 1983
L. Heigel	Test Engineer E&R Center Mechanical Branch In charge of test
A. B. Lewey	Mechanical Engineer E&R Center Mechanical Branch Assistant
J. P. Favero	Mechanical Engineer E&R Center Mechanical Branch Assistant
D. L. Kistenmacher	Representative of Stanley Consultants, Inc. Contractor for determining the discharge rate by the pressure-time (Gibson) method
M. Byrne	Representative of Allis Chalmers Corporation Turbine manufacturer
D. Clinkenbeard	Mechanical Engineer Construction Division Columbia Basin Project Project Representative

Frontispiece – *Grand Coulee Dam and Third Powerplant August 22, 1979.* Photo P801-D-80508

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CONCLUSIONS

On June 7 to 9, 1983, a performance test was conducted on the vertical-shaft, Francis-type turbine designated Unit G24 (app. 1) in Grand Coulee Third Powerplant at Grand Coulee Dam, Washington. The purpose was to determine the operating characteristics of the unit.

Results of the test indicate the performance characteristics of the turbine to be:

94.06	percent maximum efficiency, at an adjusted discharge of
29,589	cubic feet per second, at a net head of
305	feet, for an adjusted turbine output of
960,000	horsepower.

The design specification required that the turbine meet or exceed a weighted average efficiency of 92.53 percent. The weighted average efficiency was defined as follows:

$$\text{Efficiency} = \frac{0.5A + 1.5B + 7.5C + 0.5D}{10}$$

where

A, B, C, and D are values of efficiency from smooth curves at points for prototype horsepower amounts of 50, 75, and 100 percent of rated load, and full load; respectively at 305-foot head.

From this test:

A = 84.16 percent at 480,000 horsepower,
B = 90.51 percent at 720,000 horsepower,
C = 94.06 percent at 960,000 horsepower,
D = 91.19 percent at full gate,
and weighted average efficiency = 92.89 percent

The turbine exceeded the requirement by 0.36 percent.

TEST RESULTS

Turbine performance characteristics are shown in table 1 and on figure 1. Table 1 shows actual test values of power output and discharge for a net head range from 296.02 to 300.83 feet as the gate opening varies from 30 to 100 percent. Table 1 also shows discharge, power output, and efficiency adjusted to a net head of 305 feet. Adjusted values are plotted on figure 1.

Table 1. - Turbine performance, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Servomotor position %	Net head ft	Discharge ft^3/s	Output hp/1000	Adjusted to net head = 305 feet: Discharge ft^3/s	Adjusted to net head = 305 feet: Outout hp/1000	Eff. %
15	80.29	297.64	28367	896.35	28716	929.78	93.75
16	85.72	297.24	30193	956.62	30585	994.30	94.13
17	89.70	296.84	31312	985.07	31740	1026.00	93.60
18	94.67	296.42	32837	1017.90	33309	1062.43	92.35
19	99.70						
20	99.71	296.02	34210	1048.85	34725	1096.96	91.47
21	99.69	296.68	34409	1049.46	34888	1093.90	90.79
22	94.64	296.57	32721	1017.94	33183	1061.65	92.64
23	90.50	297.10	31725	990.64	32144	1030.39	92.82
24	84.68	297.43	29960	949.97	30339	986.49	94.15
25	79.39	297.46	27780	884.44	28130	918.28	94.52
26	75.00	297.42	25606	827.66	25931	859.53	95.98
27	69.79	298.51	24419	754.57	24683	779.32	91.42
28	65.08	298.81	23008	702.88	23245	724.84	90.29
29	59.99	299.21	21165	641.41	21369	660.11	89.44
30	55.17	299.78	19468	579.21	19637	594.41	87.65
31	50.39	299.56	17187	499.66	17343	513.33	85.71
32	49.74	299.71	17127	487.92	17278	500.88	83.94
33	55.20	299.41	18912	579.23	19088	595.52	90.34
34	59.70	299.24	21165	638.69	21368	657.21	89.06
35	64.68	298.82	22680	697.92	22914	719.70	90.94
36	69.59	298.50	24435	754.35	24700	779.11	91.33
37	74.50	297.68	26092	822.07	26411	852.59	93.47
38	99.69	296.14	34387	1052.45	34898	1100.00	91.27
39	94.73	296.43	32935	1017.26	33408	1061.67	92.02
40	89.83	296.73	31663	985.10	32101	1026.55	92.59
41	84.70	297.20	30130	948.14	30523	985.70	93.51
42	79.80	297.15	27966	888.43	28333	923.86	94.41
43	75.10	297.70	26256	828.43	26576	859.10	93.60
44	69.84	298.33	24714	755.65	24989	781.13	90.51
45	64.91	298.61	22870	700.82	23114	723.44	90.63
46	59.71	298.91	21007	640.39	21220	660.05	90.06
47	54.80	299.47	19154	573.84	19330	589.81	88.35
48	50.10	299.54	17003	492.95	17158	506.49	85.48
49	39.52	300.33	13225	336.31	13328	344.19	74.78
50	29.61	300.83	9326	182.38	9391	186.18	57.41
51	29.94	300.60	9304	186.39	9372	190.50	58.85
52	39.97	300.13	12967	338.63	13072	346.92	76.84

Head ratio = 305 / net head

Adjusted discharge = (discharge)(head ratio)$^{0.5}$

Adjusted horsepower = (horsepower)(head ratio)$^{1.5}$

Efficiency = (550)(adjusted horsepower) / [(adjusted discharge)(305)(γ)]

γ = weight of water = 62.279 lb/ft^3

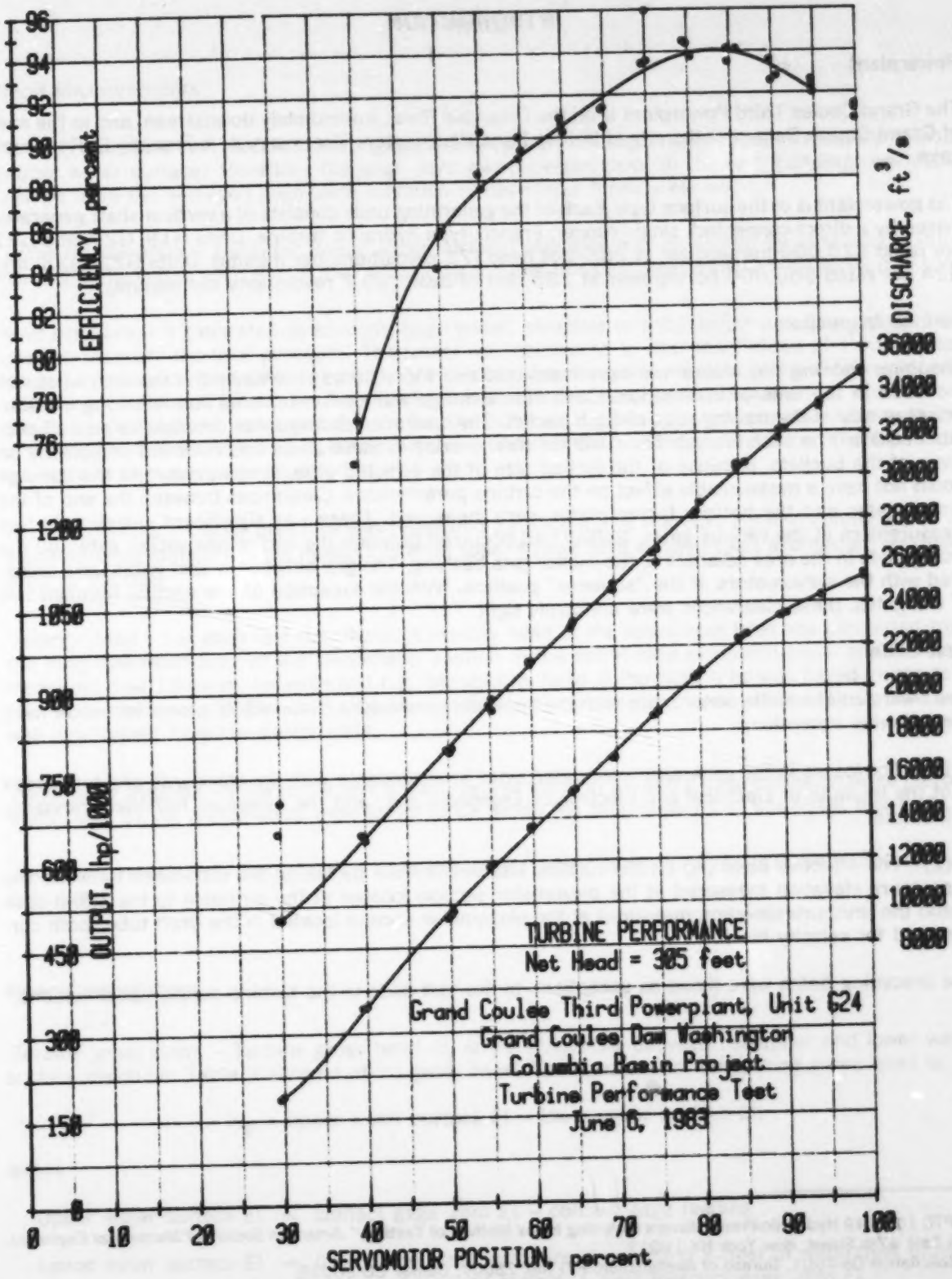

Figure 1. – Turbine performance.

INTRODUCTION

Powerplant

The Grand Coulee Third Powerplant is on the Columbia River, immediately downstream and to the east of Grand Coulee Dam near the city of Coulee Dam, Washington. The reservoir is Franklin D. Roosevelt Lake.

The powerplant is of the surface type. Each of the generating units consists of a vertical-shaft generator driven by a direct-connected, single-runner, Francis-type hydraulic turbine. Units G19, G20, and G21 are rated 820,000 horsepower at 285-foot head (72 revolutions per minute). Units G22, G23, and G24 are rated 960,000 horsepower at 285 feet of head (85.7 revolutions per minute).

Turbine Inspection

The lower wearing ring clearances were measured and found to be essentially the same as what was recorded at the time of installation. Cavitation damage was present on the runner along the low-pressure side of the trailing edge of each bucket. The cavitation damage was confined to a small area (about 50 in^2) on each bucket. The stainless steel overlay in these areas was removed completely on some of the buckets. Because of the limited size of the affected area, it was presumed the damage would not have a measureable effect on the turbine performance. Clearances between the end of the wicket gates and the bottom facing plates were measured. There was significant variation in this measurement at the various gates. Galling had occurred between the end of one wicket gate and the facing plate in the area adjacent to the wicket gate bushing. The gap between wicket gates were measured with the servomotors at the "squeeze" position. With the exception of one section between two of the gates, these clearances were uniformly tight.

Test Code

Tests were conducted in accordance with the applicable provisions of the ASME power test code[1] with the following exceptions:

(1) The losses in the generator were determined in accordance with the standards and test codes of the Institute of Electrical and Electronics Engineers, Inc., and the American National Standards Institute.

(2) The effective head (H) on the turbine was determined by taking the difference between the pressure elevation measured at the piezometer section located at the entrance to the spiral case and the pressure elevation measured at the piezometer section located in the draft tube, both corrected for velocity head.

The preceding items were listed as exceptions to the test code in the turbine supply specifications.[2]

---

[1] PTC 18-1949 **Hydraulic-Prime Movers Including Index Method of Testing,"** *American Society of Mechanical Engineers*, 345 East 47th Street, New York NY 10017.

[2] Solicitation DS-7001, Bureau of Reclamation, P O Box 25007, Denver CO 80225.

HEAD

Head Measurements

Forebay elevation. – An electric contact gage, in a temporary stilling well, was used to measure forebay (upper water surface) elevation. The gage *zero* was surveyed prior to the test. Readings were subtracted from the surveyed gage *zero* elevation to determine forebay elevation.

Tailwater elevation. – Tailwater (lower water surface) elevation was measured by obtaining a static reading at the end of each run on the mercury manometer used for measuring turbine outlet pressure.

Inlet pressure. – A calibrated deadweight gage tester, sensitive to a 0.1-lb/in^2 pressure change, was used to measure the inlet pressure. The tester was connected to four manifolded piezometer taps located in the spiral case extension piece. After installation, the *zero* elevation of the deadweight gage tester was established by survey. A static check measurement was made before the test to determine the local site weight of water and the conversion factor of indicated pounds per square inch to feet of water. The former was used to determine power input to the turbine and the latter to convert inlet pressure to inlet pressure elevation.

Outlet pressure. – Outlet pressure was measured by means of a mercury column connected to six manifolded piezometers in the multioutlet draft tube. A gage *zero* elevation was established by survey prior to the test.

Velocity head. – For each test run, the inlet velocity head at the spiral case inlet was computed from the field-calibrated area of the piezometer section in the spiral case extension piece and from the measured flow. Likewise, for each test run, the velocity head at the draft tube was based on the total sum of the net areas at the draft tube piezometer sections and the measured flow. Draft tube area was determined from the design data.

Piezometer traverse. – Prior to the test, a traverse was made at the spiral case extension piece piezometers (app. 3). All piezometers were found to be within the requirements of the ASME test code.

Penstock head loss. – Total losses from the upper water surface to the turbine entrance were calculated.

Head Computations

Turbine gross head. – Turbine gross head H_g is the difference between the upper and lower water surface elevation. Table 2 shows turbine gross head. The equation for computing gross head is:

$$H_g = \text{upper water surface El.} - \text{lower water surface El.}$$

where

Upper water surface El. = contact gage *zero* El. – contact gage reading

Lower water surface El. = (draft tube static pressure, ft-mercury) x (feet of water/feet of mercury conversion factor) + field mercury gage *zero* El.

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Turbine net head. – Turbine net head H_n is equal to the inlet pressure El. H_i plus inlet velocity head h_{vi} minus outlet presure El. h_o minus outlet velocity head H_{vo}. Inlet and outlet pressure elevations are computed from the appropriate measured pressures. Table 3 shows measured pressures and pressure elevations. Table 4 shows velocity heads and the net head. The equation for computing net H_n is:

$$H_n = H_i + H_{vi} - H_o - H_{vo}$$

where

H_i = (inlet pressure P_i) (deadweight gage tester conversion factor, app. 5) + deadweight gage tester *zero* elevation (app. 5)

$$H_i = 2.3125\ P_i + 971.17$$

H_o = (outlet pressure P_o) (specific gravity of mercury) + outlet pressure gage *zero* elevation

$$H_o = 13.576\ P_o + 907.13$$

$$H_{vi} = \frac{Q^2}{A_i^2\ 2g_2} = 17.515 \times 10^{-9}\ Q^2$$

$$H_{vo} = \frac{Q^2}{A_o^2\ 2g_3} = 1.9910 \times 10^{-9}$$

and

A_i	= 941.88	ft²	(area of spiral case extension piece at piezometer section)
A_o	= 2,793.60	ft²	(area of draft tube at piezometer sections)
g_2	= 32.1783	ft/s²	[at elevation of spiral case extension piece piezometer section, distributor centerline (app. 4)]
g_3	= 32.1785	ft/s²	[at elevation of outer end of draft tube piezometer section (app. 4)]

Penstock head loss. – Penstock head loss H_L is equal to the upper water surface elevation minus inlet pressure elevation H_i minus inlet velocity head H_{vi}. Computations and data are tabulated in table 5 and shown on figure 2. The equation for computing penstock head loss is:

$$H_L = \text{upper water surface elevation} - H_i - H_{vi}$$

Sample Computation – Run No. 20

P_i = 116.41 lb/in²
P_o = 4.08 ft-Hg
Q = 34,210 ft³/s

Draft tube static pressure = 4.10 ft-mercury
Field mercury gage *zero* El. = 907.13 ft
Feet of water/feet of mercury conversion factor = 13.576

Contact gage *zero* El. = 1316.8 feet
Contact gage reading = 53.15 feet

Upper water surface El. = 1316.8 – 53.15	1263.65 feet
Lower water surface El. = 4.10 (13.576) + 907.13	(–) 962.79
H_g = 1263.65 – 962.79	300.86 feet
H_i = 116.41 (2.3125) + 971.17	1240.37 feet
H_o = 4.08 (13.576) + 907.13	(–) 962.52
H_{vi} = 17.515 x 10^{-9} (34,210)²	20.50
H_{vo} = 1.9910 x 10^{-9} (34,210)²	(–) 2.33
H_n = 1240.37 + 20.5 – 962.62 – 2.33	296.02 feet
H_L = 1263.65 – 1240.37 – 20.50	2.78 feet

Table 2. - Turbine gross head, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Servomotor position %	Contact gage reading ft	Upper water surface elevation ft	Draft tube static pressure Hg, ft	Lower water surface elevation ft	Gross head ft
15	80.29	53.19	1263.61	4.08	962.52	301.09
16	85.72	53.18	1263.62	4.06	962.25	301.37
17	89.70	53.15	1263.65	4.08	962.52	301.13
18	94.67	53.09	1263.71	4.10	962.79	300.92
19	99.70	53.11	1263.69	4.08	962.52	301.17
20	99.71	53.15	1263.65	4.10	962.79	300.86
21	99.69	53.01	1263.79	4.06	962.25	301.54
22	94.64	53.04	1263.76	4.10	962.79	300.97
23	90.50	53.06	1263.74	4.09	962.66	301.08
24	84.68	52.95	1263.85	4.09	962.66	301.19
25	79.39	52.65	1263.85	4.09	962.66	301.19
26	75.00	52.66	1263.84	4.09	962.66	301.18
27	69.79	52.66	1263.84	4.11	962.93	300.91
28	65.08	52.72	1263.78	4.07	962.38	301.40
29	59.99	52.74	1263.76	4.10	962.79	300.97
30	55.17	52.71	1263.79	4.10	962.79	301.00
31	50.39	52.50	1264.00	4.11	962.93	301.07
32	49.74	52.47	1264.03	4.11	962.93	301.10
33	55.20	52.40	1264.10	4.10	962.79	301.31
34	59.70	52.45	1264.05	4.11	962.93	301.12
35	64.68	52.48	1264.02	4.10	962.79	301.23
36	69.59	52.50	1264.00	4.11	962.93	301.07
37	74.50	52.59	1263.91	4.11	962.93	300.98
38	99.69	52.62	1263.88	4.13	963.20	300.68
39	94.73	52.50	1264.00	4.13	963.20	300.80
40	89.83	52.50	1264.00	4.12	963.06	300.94
41	84.70	52.54	1263.96	4.12	963.06	300.90
42	79.80	52.52	1263.98	4.13	963.20	300.78
43	75.10	52.54	1263.96	4.13	963.20	300.76
44	69.84	52.50	1264.00	4.14	963.33	300.67
45	64.91	52.36	1264.14	4.14	963.33	300.81
46	59.71	52.37	1264.13	4.13	963.20	300.93
47	54.80	52.29	1264.21	4.12	963.06	301.15
48	50.10	52.34	1264.16	4.12	963.06	301.10
49	39.52	52.30	1264.20	4.12	963.06	301.14
50	29.61	52.28	1264.22	4.12	963.06	301.16
51	29.94	52.26	1264.24	4.12	963.06	301.18
52	39.97	52.25	1264.25	4.14	963.33	300.92

Hg, ft = feet of mercury

Table 3. - Inlet and outlet pressures, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Servomotor position %	Inlet		Outlet	
		Pressure lb/in^2	Elevation ft	Pressure Hg, ft	Elevation ft
15	80.29	119.51	1247.54	4.07	962.38
16	85.72	118.56	1245.34	4.06	962.25
17	89.70	117.98	1244.00	4.07	962.38
18	94.67	117.26	1242.33	4.09	962.66
19	99.70	116.45	1240.46	4.10	962.79
20	99.71	116.41	1240.37	4.08	962.52
21	99.69	116.43	1240.41	4.05	962.11
22	94.64	117.26	1242.33	4.07	962.38
23	90.50	117.98	1244.00	4.08	962.52
24	84.68	118.85	1246.01	4.08	962.52
25	79.39	119.71	1248.00	4.08	962.52
26	75.00	120.47	1249.76	4.08	962.52
27	69.79	121.34	1251.77	4.08	962.52
28	65.08	121.92	1253.11	4.08	962.52
29	59.99	122.70	1254.91	4.09	962.66
30	55.17	123.35	1256.42	4.08	962.52
31	50.39	124.11	1258.17	4.13	963.20
32	49.74	124.19	1258.36	4.13	963.20
33	55.20	123.51	1256.79	4.11	962.93
34	59.70	122.83	1255.21	4.11	962.93
35	64.68	122.20	1253.76	4.11	962.93
36	69.59	121.51	1252.16	4.11	962.93
37	74.50	120.65	1250.17	4.12	963.06
38	99.69	116.56	1240.72	4.11	962.93
39	94.73	117.40	1242.66	4.12	963.06
40	89.83	118.14	1244.37	4.13	963.20
41	84.70	118.92	1246.17	4.12	963.06
42	79.80	119.80	1248.21	4.13	963.20
43	75.10	120.60	1250.06	4.12	963.06
44	69.84	121.52	1252.19	4.14	963.33
45	64.91	122.17	1253.69	4.13	963.20
46	59.71	122.85	1255.26	4.13	963.20
47	54.80	123.59	1256.97	4.13	963.20
48	50.10	124.20	1258.38	4.14	963.33
49	39.52	125.25	1260.81	4.13	963.20
50	29.61	126.00	1262.55	4.12	963.06
51	29.94	125.96	1262.45	4.13	963.20
52	39.97	125.15	1260.58	4.12	963.06

Hg, ft = feet of mercury

Table 4. - Turbine net head, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Discharge ft^3/s	Inlet pressure elevation ft	Inlet velocity head ft	Outlet pressure elevation ft	Outlet velocity head ft	Net head ft
15	28367	1247.54	14.09	962.38	1.60	297.64
16	30193	1245.34	15.97	962.25	1.82	297.24
17	31312	1244.00	17.17	962.38	1.95	296.84
18	32837	1242.33	18.89	962.66	2.15	296.42
19		1240.46		962.79		
20	34210	1240.37	20.50	962.52	2.33	296.02
21	34409	1240.41	20.74	962.11	2.36	296.68
22	32721	1242.33	18.75	962.38	2.13	296.57
23	31725	1244.00	17.63	962.52	2.00	297.10
24	29960	1246.01	15.72	962.52	1.79	297.43
25	27780	1248.00	13.52	962.52	1.54	297.46
26	25606	1249.76	11.48	962.52	1.31	297.42
27	24419	1251.77	10.44	962.52	1.19	298.51
28	23008	1253.11	9.27	962.52	1.05	298.81
29	21165	1254.91	7.85	962.66	0.89	299.21
30	19468	1256.42	6.64	962.52	0.75	299.78
31	17187	1258.17	5.17	963.20	0.59	299.56
32	17127	1258.36	5.14	963.20	0.58	299.71
33	18912	1256.79	6.26	962.93	0.71	299.41
34	21165	1255.21	7.85	962.93	0.89	299.24
35	22680	1253.76	9.01	962.93	1.02	298.82
36	24435	1252.16	10.46	962.93	1.19	298.50
37	26092	1250.17	11.92	963.06	1.36	297.68
38	34387	1240.72	20.71	962.93	2.35	296.14
39	32935	1242.66	19.00	963.06	2.16	296.43
40	31663	1244.37	17.56	963.20	2.00	296.73
41	30130	1246.17	15.90	963.06	1.81	297.20
42	27966	1248.21	13.70	963.20	1.56	297.15
43	26256	1250.06	12.07	963.06	1.37	297.70
44	24714	1252.19	10.70	963.33	1.22	298.33
45	22870	1253.69	9.16	963.20	1.04	298.61
46	21007	1255.26	7.73	963.20	0.88	298.91
47	19154	1256.97	6.43	963.20	0.73	299.47
48	17003	1258.38	5.06	963.33	0.58	299.54
49	13225	1260.81	3.06	963.20	0.35	300.33
50	9326	1262.55	1.52	963.06	0.17	300.83
51	9304	1262.45	1.52	963.20	0.17	300.60
52	12967	1260.58	2.95	963.06	0.33	300.13

Table 5. - Penstock head loss, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Servomotor position %	Upper water surface elevation ft	Penstock pressure elevation ft	Inlet velocity head ft	Penstock head loss ft	Discharge ft^3/s
15	80.29	1263.61	1247.54	14.09	1.98	28367
16	85.72	1263.62	1245.34	15.97	2.31	30193
17	89.70	1263.65	1244.00	17.17	2.48	31312
18	94.67	1263.71	1242.33	18.89	2.49	32837
19	99.70	1263.69	1240.46			
20	99.71	1263.65	1240.37	20.50	2.78	34210
21	99.69	1263.79	1240.41	20.74	2.64	34409
22	94.64	1263.76	1242.33	18.75	2.67	32721
23	90.50	1263.74	1244.00	17.63	2.11	31725
24	84.68	1263.85	1246.01	15.72	2.12	29960
25	79.39	1263.85	1248.00	13.52	2.33	27780
26	75.00	1263.84	1249.76	11.48	2.60	25606
27	69.79	1263.84	1251.77	10.44	1.63	24419
28	65.08	1263.78	1253.11	9.27	1.40	23008
29	59.99	1263.76	1254.91	7.85	1.00	21165
30	55.17	1263.79	1256.42	6.64	0.73	19468
31	50.39	1264.00	1258.17	5.17	0.65	17187
32	49.74	1264.03	1258.36	5.14	0.53	17127
33	55.20	1264.10	1256.79	6.26	1.05	18912
34	59.70	1264.05	1255.21	7.85	0.99	21165
35	64.68	1264.02	1253.76	9.01	1.25	22680
36	69.59	1264.00	1252.16	10.46	1.38	24435
37	74.50	1263.91	1250.17	11.92	1.81	26092
38	99.69	1263.88	1240.72	20.71	2.45	34387
39	94.73	1264.00	1242.66	19.00	2.34	32935
40	89.83	1264.00	1244.37	17.56	2.07	31663
41	84.70	1263.96	1246.17	15.90	1.89	30130
42	79.80	1263.98	1248.21	13.70	2.07	27966
43	75.10	1263.96	1250.06	12.07	1.83	26256
44	69.84	1264.00	1252.19	10.70	1.12	24714
45	64.91	1264.14	1253.69	9.16	1.29	22870
46	59.71	1264.13	1255.26	7.73	1.14	21007
47	54.80	1264.21	1256.97	6.43	0.81	19154
48	50.10	1264.16	1258.38	5.06	0.71	17003
49	39.52	1264.20	1260.81	3.06	0.33	13225
50	29.61	1264.22	1262.55	1.52	0.15	9326
51	29.94	1264.24	1262.45	1.52	0.27	9304
52	39.97	1264.25	1260.58	2.95	0.73	12967

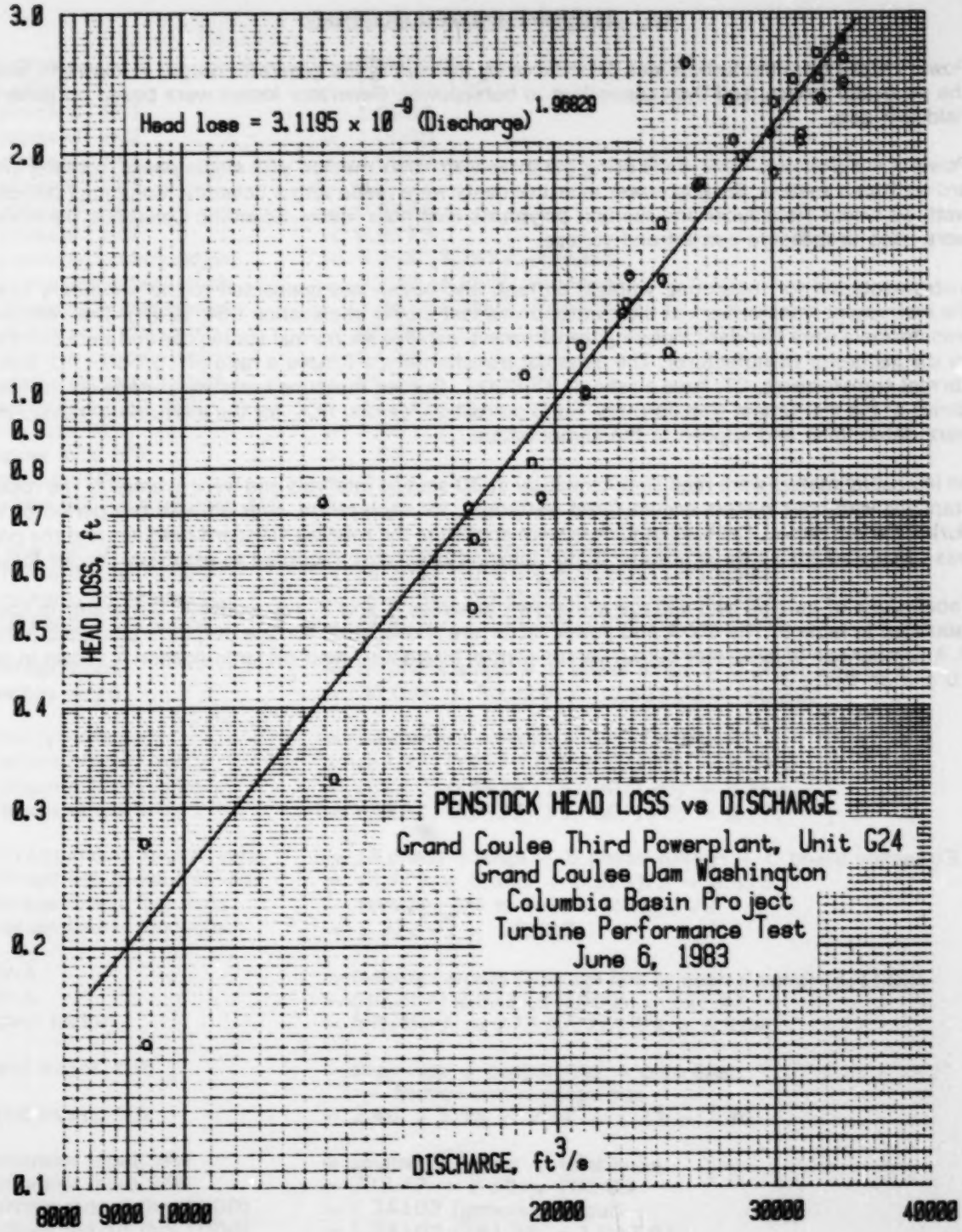


Figure 2. – Penstock head loss versus discharge.

TURBINE POWER OUTPUT

Power output from the turbine was determined by measuring the generator output in kilowatts, adding the generator losses, and then converting to horsepower. Generator losses were based on generator field test data.

Power measurements were made using the three-wattmeter method with single-phase, rotating standard watt-hour meters. Backup power measurements were made with a Scientific Columbus polyphase watt, watt-hour transducer and the unit polyphase watt-hour meter. Scientific Columbus transducers were used to measure current and voltage.

Instrumentation for measuring voltage, current, and power was connected to the secondary side of the instrument transformers at the control board test blocks at elevation 968.12 (ft). The instrument transformers were standard metering transformers installed for normal station use and were calibrated by the generator manufacturer. The potential transformers, PT, have a ratio of 15,000:120; and the current transformers, CT, have a ratio of 35,000:5. Burden measurements were made on the secondaries of the instrument transformers. Ratio correction factors, RCF, for the instrument transformers were determined and applied to the computations.

All indicating meters were read simultaneously at 30-second intervals and were averaged. The rotating standard watt-hour meters accumulated watthours, for each phase, over a measured period of time during the run period. Calibration factors were applied to the rotating standard readings and the power was calculated for all three phases. Stator temperatures were recorded to establish copper losses.

Tabulations of current and voltage are shown in tables 6 and 7, respectively. Generator output is tabulated in table 8. The MV·A and power factor are shown also. Turbine output is tabulated in table 9. A comparison of generator output versus control board watt-hour meter indication is shown in table 10 and on figure 3.

Sample Computation — Run No. 20

CT ratio	= 35,000/5
PT ratio	= 15,000/120
A phase CT RCF	= 1.0000
B phase CT RCF	= 1.0000
C phase CT RCF	= 1.0000
A phase PT RCF	= 0.9978
B phase PT RCF	= 0.9978
C phase PT RCF	= 0.9975
A phase secondary amps	= 4.298 (4.2977, rounded)
B phase secondary amps	= 4.330 (4.2000, rounded)
C phase secondary amps	= 4.361 (4.3607, rounded)
A phase secondary volts	= 67.98
B phase secondary volts	= 67.10
C phase secondary volts	= 66.34
Generator output, MW	= 773.47
Stray loss, MW	= 2.46
Copper loss, MW	= 1.55
Core loss, MW	= 2.14
Friction and windage loss, MW	= 1.73
Primary amps	= (secondary amps) (RCF) (CT Ratio)
A phase primary amps	= (4.298) 1.0000 (35,000/5) = 30,084
B phase primary amps	= (4.330) 1.0000 (35,000/5) = 30,310
C phase primary amps	= (4.361) 1.0000 (35,000/5) = 30,525
Average amps	= (A phase amps + B phase amps + C phase amps)/3
Average amps	= (30,084 + 30,310 + 30,525)/3 = 30,307
Primary voltage	= (secondary voltage) (RCF) (PT Ratio)
A phase primary volts	= (67.98) 0.9978 (15,000/120) = 8,479
B phase primary volts	= (67.10) 0.9978 (15,000/120) = 8,369
C phase primary volts	= (66.34) 0.9975 (15,000/120) = 8,271
Average line to neutral volts	= (A phase voltage + B phase voltage + C phase voltage)/3
Average line to neutral volts	= (8,479 + 8,369 + 8,271)/3 = 8,373
Average line to line volts	= (average line to neutral voltage)$\sqrt{3}$
Average line to line volts	= 8,373$\sqrt{3}$ = 14,503
MV·A	= (average amps) (average line to neutral volts) (3/1000)
MV·A	= (30,307) 8,373 (3/1000) = 761.27
Power factor	= MW/MV·A = 773.47/761.59 = 0.984
Total losses, MW	= stray loss + copper loss + core loss + friction and windage loss
Total losses, MW	= 2.46 + 1.55 + 2.14 + 1.73 = 7.88
Generator input, MW	= generator output + total losses
Generator input, MW	= 773.47 + 7.88 = 781.35
Turbine output (hp/1000)	= 1.34102 (generator input)
Turbine output (hp/1000)	= 1.34102 (781.35 = 1,047.81

CT Current transformer, PT potential transformer, and RCF ratio correction factor.

Table 6. - Generator current transformer output, and average phase amperes, turbine performance test -Grand Coulee Third Powerplant, Unit G24

Run No.	Current Transformer Secondary			Current Transformer Primary			Average amps
	A phase amps	B phase amps	C phase amps	A phase amps	B phase amps	C phase amps	
15	3.640	3.669	3.697	25480	25683	25878	25680
16	3.903	3.932	3.960	27320	27523	27722	27521
17	4.022	4.052	4.080	28154	28365	28560	28360
18	4.151	4.183	4.212	29058	29281	29481	29273
19	4.277	4.311	4.339	29936	30175	30372	30161
20	4.298	4.330	4.361	30084	30310	30525	30307
21	4.297	4.329	4.360	30079	30300	30522	30300
22	4.163	4.194	4.226	29143	29360	29581	29362
23	4.051	4.081	4.113	28354	28566	28793	28571
24	3.878	3.907	3.939	27145	27349	27574	27356
25	3.587	3.613	3.646	25106	25293	25524	25308
26	3.364	3.389	3.423	23549	23722	23958	23743
27	3.039	3.061	3.095	21272	21430	21668	21457
28	2.839	2.860	2.895	19871	20022	20266	20053
29	2.558	2.578	2.612	17906	18046	18282	18078
30	2.312	2.330	2.365	16182	16310	16557	16350
31	1.985	1.999	2.031	13897	13995	14218	14037
32	1.954	1.970	2.000	13675	13787	14002	13821
33	2.339	2.356	2.388	16372	16492	16713	16525
34	2.579	2.598	2.629	18055	18185	18401	18213
35	2.830	2.850	2.881	19811	19953	20167	19977
36	3.031	3.051	3.081	21220	21358	21569	21382
37	3.322	3.345	3.375	23251	23413	23623	23429
38	4.288	4.317	4.347	30019	30218	30430	30222
39	4.141	4.168	4.199	28988	29177	29391	29185
40	4.009	4.037	4.068	28062	28262	28473	28266
41	3.847	3.874	3.904	26929	27121	27326	27125
42	3.597	3.621	3.651	25179	25346	25559	25362
43	3.337	3.359	3.389	23358	23515	23724	23532
44	3.033	3.054	3.083	21233	21379	21581	21398
45	2.828	2.849	2.879	19797	19943	20151	19964
46	2.560	2.579	2.608	17917	18053	18253	18074
47	2.301	2.320	2.349	16105	16238	16445	16263
48	1.959	1.976	2.006	13712	13829	14044	13862
49	1.318	1.331	1.362	9227	9317	9531	9359
50	0.686	0.695	0.725	4799	4862	5078	4913
51	0.712	0.725	0.753	4981	5077	5273	5110
52	1.354	1.369	1.397	9479	9584	9781	9615

Table 7. - Generator potential transformer output and averae phase voltage, turbine performance test -Grand Coulee Third Powerplant, Unit G24

Run No.	Potential Transformer Secondary A phase volts	Potential Transformer Secondary B phase volts	Potential Transformer Secondary C phase volts	Potential Transformer Primary A phase volts	Potential Transformer Primary B phase volts	Potential Transformer Primary C phase volts	Line to neutral average volts	Line to line average volts
15	68.24	67.36	66.57	8512	8401	8300	8404	14557
16	68.20	67.31	66.53	8506	8395	8296	8399	14548
17	68.15	67.27	66.48	8500	8390	8289	8393	14537
18	68.19	67.32	66.53	8505	8397	8296	8399	14548
19	68.14	67.26	66.48	8499	8390	8289	8393	14537
20	67.98	67.10	66.34	8479	8369	8271	8373	14503
21	68.02	67.15	66.37	8484	8375	8275	8378	14512
22	68.04	67.17	66.37	8487	8377	8275	8380	14514
23	68.07	67.20	66.39	8490	8382	8278	8383	14520
24	68.13	67.25	66.46	8497	8388	8287	8391	14533
25	68.40	67.52	66.71	8531	8422	8318	8424	14590
26	68.53	67.64	66.84	8547	8436	8334	8439	14617
27	68.70	67.83	67.02	8568	8460	8357	8462	14656
28	68.81	67.94	67.12	8582	8474	8369	8475	14679
29	68.84	67.95	67.15	8586	8476	8373	8478	14685
30	69.00	68.12	67.32	8607	8496	8394	8499	14720
31	68.97	68.07	67.28	8602	8490	8389	8494	14711
32	68.83	67.91	67.12	8585	8470	8369	8474	14678
33	68.79	67.91	67.09	8580	8470	8366	8472	14673
34	68.68	67.80	67.00	8566	8457	8355	8459	14651
35	68.55	67.65	66.86	8549	8438	8336	8441	14620
36	68.72	67.83	67.05	8571	8460	8360	8464	14660
37	68.56	67.67	66.88	8551	8440	8339	8444	14625
38	68.13	67.27	66.48	8498	8391	8290	8393	14537
39	68.33	67.45	66.69	8523	8413	8315	8417	14579
40	68.37	67.50	66.71	8527	8418	8318	8421	14586
41	68.56	67.69	66.92	8552	8442	8344	8446	14629
42	68.75	67.85	67.05	8575	8462	8360	8466	14663
43	68.86	67.97	67.16	8588	8478	8374	8480	14688
44	68.92	68.00	67.20	8596	8482	8379	8486	14698
45	69.12	68.21	67.42	8621	8507	8406	8512	14742
46	69.12	68.19	67.41	8620	8505	8405	8510	14740
47	69.27	68.35	67.55	8639	8525	8423	8529	14773
48	69.31	68.41	67.62	8644	8532	8432	8536	14785
49	69.57	68.63	67.86	8677	8560	8461	8566	14837
50	69.67	68.73	67.94	8689	8573	8471	8578	14857
51	69.45	68.53	67.72	8663	8547	8444	8551	14812
52	69.23	68.31	67.52	8635	8519	8418	8524	14764

Table 8. - Generator output, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Servomotor position %	Average amps	Average line to neutral volts	Generator output MW	Generator output MVA	Power factor %
15	80.3	25680	8404	661.08	647.49	0.979
16	85.7	27521	8399	705.50	693.46	0.983
17	89.7	28360	8393	726.48	714.08	0.983
18	94.7	29273	8399	750.67	737.62	0.983
19	99.7	30161	8393	772.45	759.39	0.983
20	99.7	30307	8373	773.47	761.27	0.984
21	99.7	30300	8378	773.89	761.59	0.984
22	94.6	29362	8380	750.69	738.12	0.983
23	90.5	28571	8383	730.57	718.55	0.984
24	84.7	27356	8391	700.60	688.61	0.983
25	79.4	25308	8424	652.31	639.54	0.980
26	75.0	23743	8439	610.36	601.10	0.985
27	69.8	21457	8462	556.37	544.67	0.979
28	65.1	20053	8475	518.13	509.84	0.984
29	60.0	18078	8478	472.66	459.81	0.973
30	55.2	16350	8499	426.58	416.86	0.977
31	50.4	14037	8494	367.63	357.66	0.973
32	49.7	13821	8474	358.93	351.38	0.979
33	55.2	16525	8472	426.60	420.00	0.985
34	59.7	18213	8459	470.64	462.20	0.982
35	64.7	19977	8441	514.47	505.89	0.983
36	69.6	21382	8464	556.23	542.92	0.976
37	74.5	23429	8444	606.27	593.47	0.979
38	99.7	30222	8393	776.22	760.95	0.980
39	94.7	29185	8417	750.24	736.96	0.982
40	89.8	28266	8421	726.52	714.08	0.983
41	84.7	27125	8446	699.27	687.29	0.983
42	79.8	25362	8466	655.22	644.11	0.983
43	75.1	23532	8480	610.95	598.66	0.980
44	69.8	21398	8486	557.17	544.72	0.978
45	64.9	19964	8512	516.57	509.77	0.987
46	59.7	18074	8510	471.88	461.44	0.978
47	54.8	16263	8529	422.56	416.13	0.985
48	50.1	13862	8536	362.61	354.98	0.979
49	39.5	9359	8566	246.33	240.50	0.976
50	29.6	4913	8578	131.85	126.42	0.959
51	29.9	5110	8551	134.86	131.10	0.972
52	40.0	9615	8524	248.07	245.87	0.991

Table 9. - Generator input/turbine output, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Generator output MW	Stray loss MW	Copper loss MW	Core loss MW	Total loss* MW	Generator input MW	Turbine output hp/1000
15	661.08	1.77	1.67	2.16	7.33	668.41	896.35
16	705.50	2.03	1.93	2.16	7.85	713.35	956.62
17	726.48	2.15	2.06	2.15	8.09	734.57	985.07
18	750.67	2.29	2.20	2.16	8.38	759.05	1017.90
19	772.45	2.43	2.34	2.15	8.65	781.10	1047.47
20	773.47	2.46	2.33	2.14	8.66	782.13	1048.85
21	773.89	2.46	2.36	2.14	8.69	782.58	1049.46
22	750.69	2.31	2.21	2.14	8.39	759.08	1017.94
23	730.57	2.18	2.09	2.15	8.15	738.72	990.64
24	700.60	2.00	1.91	2.15	7.79	708.39	949.97
25	652.31	1.71	1.61	2.17	7.22	659.53	884.44
26	610.36	1.51	1.40	2.19	6.83	617.19	827.66
27	556.37	1.23	1.15	2.20	6.31	562.68	754.57
28	518.13	1.08	0.99	2.21	6.01	524.14	702.88
29	472.66	0.88	0.81	2.22	5.64	478.30	641.41
30	426.58	0.72	0.66	2.23	5.34	431.92	579.21
31	367.63	0.53	0.48	2.23	4.97	372.60	499.66
32	358.93	0.51	0.46	2.21	4.91	363.84	487.92
33	426.60	0.73	0.66	2.21	5.33	431.93	579.23
34	470.64	0.89	0.81	2.20	5.63	476.27	638.69
35	514.47	1.07	0.98	2.19	5.97	520.44	697.92
36	556.23	1.22	1.13	2.21	6.29	562.52	754.35
37	606.27	1.47	1.36	2.19	6.75	613.02	822.07
38	776.22	2.44	2.27	2.15	8.59	784.81	1052.45
39	750.24	2.28	2.15	2.17	8.33	758.57	1017.26
40	726.52	2.14	2.03	2.17	8.07	734.59	985.10
41	699.27	1.97	1.87	2.19	7.76	707.03	948.14
42	655.22	1.72	1.62	2.21	7.28	662.50	888.43
43	610.95	1.48	1.38	2.22	6.81	617.76	828.43
44	557.17	1.23	1.14	2.22	6.32	563.49	755.65
45	516.57	1.07	0.99	2.24	6.03	522.60	700.82
46	471.88	0.88	0.81	2.24	5.66	477.54	640.39
47	422.56	0.71	0.65	2.26	5.35	427.91	573.84
48	362.61	0.52	0.47	2.26	4.98	367.59	492.95
49	246.33	0.24	0.21	2.28	4.46	250.79	336.31
50	131.85	0.07	0.06	2.29	4.15	136.00	182.38
51	134.86	0.07	0.06	2.27	4.13	138.99	186.39
52	248.07	0.25	0.22	2.25	4.45	252.52	338.63

* Friction and windage loss of 1.73 megawatts is included.

Table 10. - Generator output comparison, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Servomotor position %	Generator input MW	Generator losses MW	Generator outout MW	Controlboard indication MW
15	80.29	668.41	7.33	661.08	663.16
16	85.72	713.35	7.85	705.50	709.19
17	89.70	734.57	8.09	726.48	726.92
18	94.67	759.05	8.38	750.67	756.00
19	99.70	781.10	8.65	772.45	776.18
20	99.71	782.13	8.66	773.47	779.38
21	99.69	782.58	8.69	773.89	776.18
22	94.64	759.08	8.39	750.69	754.49
23	90.50	738.72	8.15	730.57	731.14
24	84.68	708.39	7.79	700.60	700.00
25	79.39	659.53	7.22	652.31	651.72
26	75.00	617.19	6.83	610.36	611.65
27	69.79	562.68	6.31	556.37	554.25
28	65.08	524.14	6.01	518.13	514.99
29	59.99	478.30	5.64	472.66	471.32
30	55.17	431.92	5.34	426.58	425.20
31	50.39	372.60	4.97	367.63	366.28
32	49.74	363.84	4.91	358.93	356.27
33	55.20	431.93	5.33	426.60	424.72
34	59.70	476.27	5.63	470.64	467.82
35	64.68	520.44	5.97	514.47	511.50
36	69.59	562.52	6.29	556.23	553.44
37	74.50	613.02	6.75	606.27	604.80
38	99.69	784.81	8.59	776.22	774.59
39	94.73	758.57	8.33	750.24	751.49
40	89.83	734.59	8.07	726.52	728.32
41	84.70	707.03	7.76	699.27	700.00
42	79.80	662.50	7.28	655.22	655.11
43	75.10	617.76	6.81	610.95	611.65
44	69.84	563.49	6.32	557.17	553.44
45	64.91	522.60	6.03	516.57	512.20
46	59.71	477.54	5.66	471.88	469.57
47	54.80	427.91	5.35	422.56	420.00
48	50.10	367.59	4.98	362.61	359.66
49	39.52	250.79	4.46	246.33	244.03
50	29.61	136.00	4.15	131.85	130.22
51	29.94	138.99	4.13	134.86	133.37
52	39.97	252.52	4.45	248.07	249.01

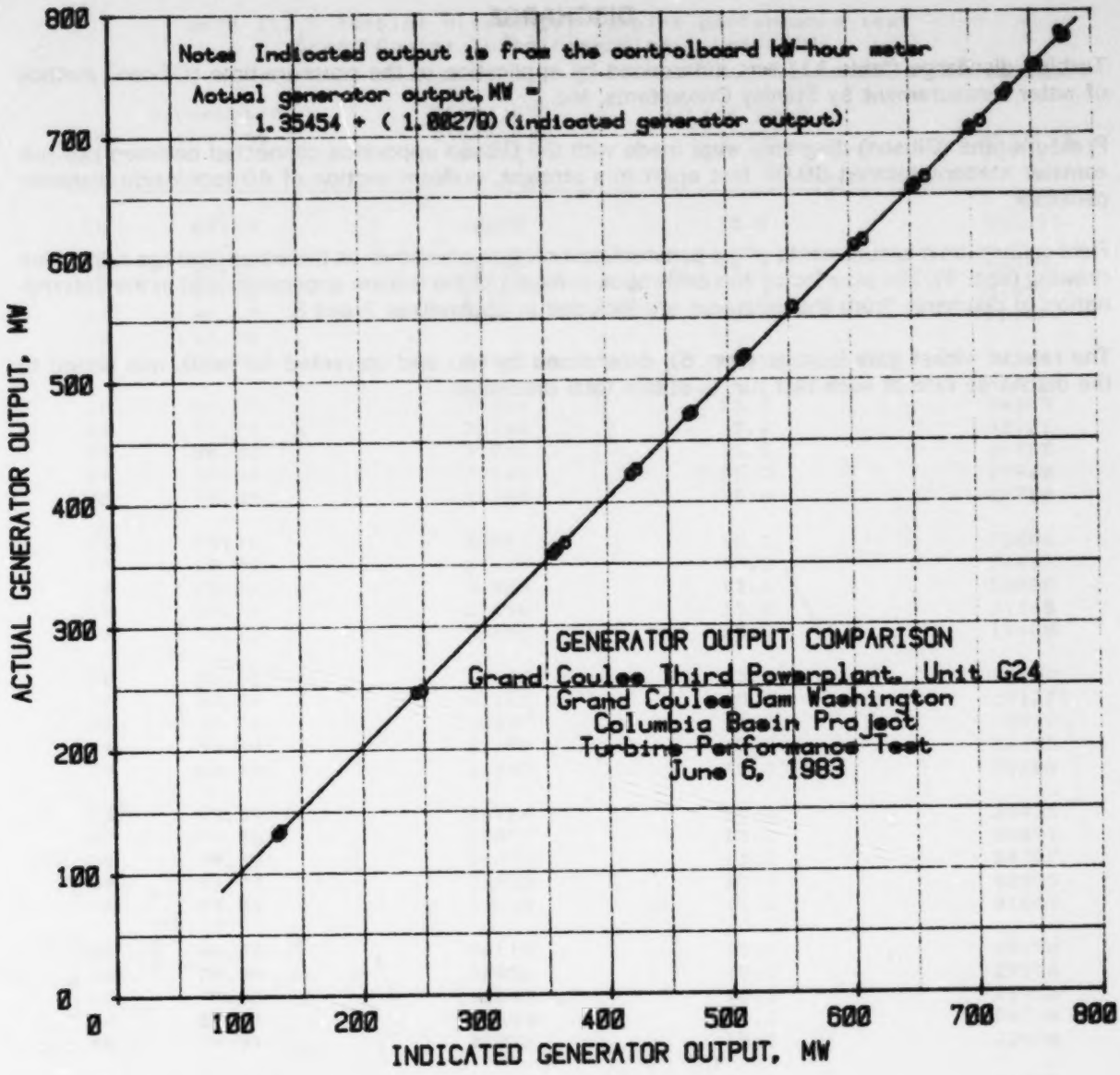


Figure 3. – Generator output comparison.

DISCHARGE

Turbine discharge (table 11) was determined by application of the pressure-time (Gibson) method of water measurement by Stanley Consultants, Inc.

Pressure-time (Gibson) diagrams were made with the Gibson apparatus connected between two piezometer stations located 80.06 feet apart in a straight, uniform section of 40-foot-inside-diameter penstock.

Field calibration measurements of the penstock test section are shown on the water passage calibration drawing (app. 9). The pipe factor and calibration constant of the Gibson apparatus used in the determination of discharge from the diagrams are included in appendixes 7 and 8.

The rate of wicket gate leakage (app. 6), determined by test and corrected for head, was added to the discharge rate of each test run to obtain total discharge.

Table 11. - Turbine discharge, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Servomotor opening %	"Gibson" discharge ft^3/s	Wicket gate leakage ft^3/s	Discharge ft^3/s
15	80.29	28352	15.2	28367
16	85.72	30178	15.3	30193
17	89.70	31297	15.3	31312
18	94.67	32822	15.2	32837
19	99.70			
20	99.71	34195	15.1	34210
21	99.69	34394	15.2	34409
22	94.64	32706	15.2	32721
23	90.50	31710	15.1	31725
24	84.68	29945	15.3	29960
25	79.39	27765	15.2	27780
26	75.00	25591	15.1	25606
27	69.79	24404	15.2	24419
28	65.08	22993	15.1	23008
29	59.99	21150	15.2	21165
30	55.17	19453	15.3	19468
31	50.39	17172	15.2	17187
32	49.74	17112	15.3	17127
33	55.20	18897	15.2	18912
34	59.70	21150	15.2	21165
35	64.68	22665	15.3	22680
36	69.59	24420	15.2	24435
37	74.50	26077	15.2	26092
38	99.69	34372	15.2	34387
39	94.73	32920	15.1	32935
40	89.83	31648	15.2	31663
41	84.70	30115	15.2	30130
42	79.80	27951	15.2	27966
43	75.10	26241	15.3	26256
44	69.84	24699	15.2	24714
45	64.91	22855	15.2	22870
46	59.71	20992	15.2	21007
47	54.80	19139	15.2	19154
48	50.10	16988	15.2	17003
49	39.52	13210	15.2	13225
50	29.61	9311	15.2	9326
51	29.94	9289	15.2	9304
52	39.97	12952	15.2	12967

Flow Index Calibration

Pressure differential measurements were made across the Winter-Kennedy piezometer taps using a differential mercury manometer. The Winter-Kennedy taps then were calibrated by correlating discharge to differential pressure. This correlation was made by using the method of least squares; i.e., fitting the data to the equation $Q = CD^e$.

For Grand Coulee Third Powerplant Unit G-24, C and e were determined to be:

Taps	C	e	$Q = CD^e$
A-D	7726.3588	0.5063	$Q = 7726.3588\ D^{0.5063}$
B-D	8337.8116	0.5043	$Q = 8337.8116\ D^{0.5043}$
C-D	9204.0686	0.5012	$Q = 9204.0686\ D^{0.5012}$

Tabulated data and calibration curves are shown in table 12 and on figures 4, 5, and 6, respectively.

Table 12. - Turbine discharge index calibration, turbine performance test - Grand Coulee Third Powerplant, Unit G24

Run No.	Servomotor opening %	Total Discharge ft^3/s	Piezometer differentials A-D Hg, in	B-D Hg, in	C-D Hg, in
15	80.29	28367	12.96	12.30	9.42
16	85.72	30193	14.86	12.80	10.60
17	89.70	31312	15.90	13.82	11.56
18	94.67	32837	17.22	15.08	12.68
19	99.70				
20	99.71	34210	19.08	16.48	13.54
21	99.69	34409	18.90	16.24	13.50
22	94.64	32721	17.52	15.00	12.38
23	90.50	31725	16.14	13.98	11.56
24	84.68	29960	14.46	12.54	10.48
25	79.39	27780	12.72	11.10	9.24
26	75.00	25606	11.32	9.84	8.24
27	69.79	24419	9.90	8.40	7.02
28	65.08	23008	8.50	7.40	6.16
29	59.99	21165	7.20	6.22	5.18
30	55.17	19468	5.96	5.20	4.38
31	50.39	17187	4.80	4.24	3.56
32	49.74	17127	4.68	4.08	3.48
33	55.20	18912	6.00	5.14	4.26
34	59.70	21165	7.22	6.48	5.26
35	64.68	22680	8.48	6.48	6.20
36	69.59	24435	9.66	8.36	6.96
37	74.50	26092	11.16	9.70	8.14
38	99.69	34387	19.00	16.36	13.70
39	94.73	32935	17.44	15.20	12.66
40	89.83	31663	15.98	13.96	11.58
41	84.70	30130	14.38	12.50	10.52
42	79.80	27966	12.74	11.18	9.36
43	75.10	26256	11.44	10.12	8.34
44	69.84	24714	9.72	8.50	7.14
45	64.91	22870	8.46	7.28	6.08
46	59.71	21007	7.18	6.30	5.18
47	54.80	19154	5.94	5.12	4.32
48	50.10	17003	4.82	4.16	3.40
49	39.52	13225	2.98	2.52	2.04
50	29.61	9326	1.40	1.20	1.00
51	29.94	9304	1.44	1.28	1.00
52	39.97	12967	2.96	2.54	2.06

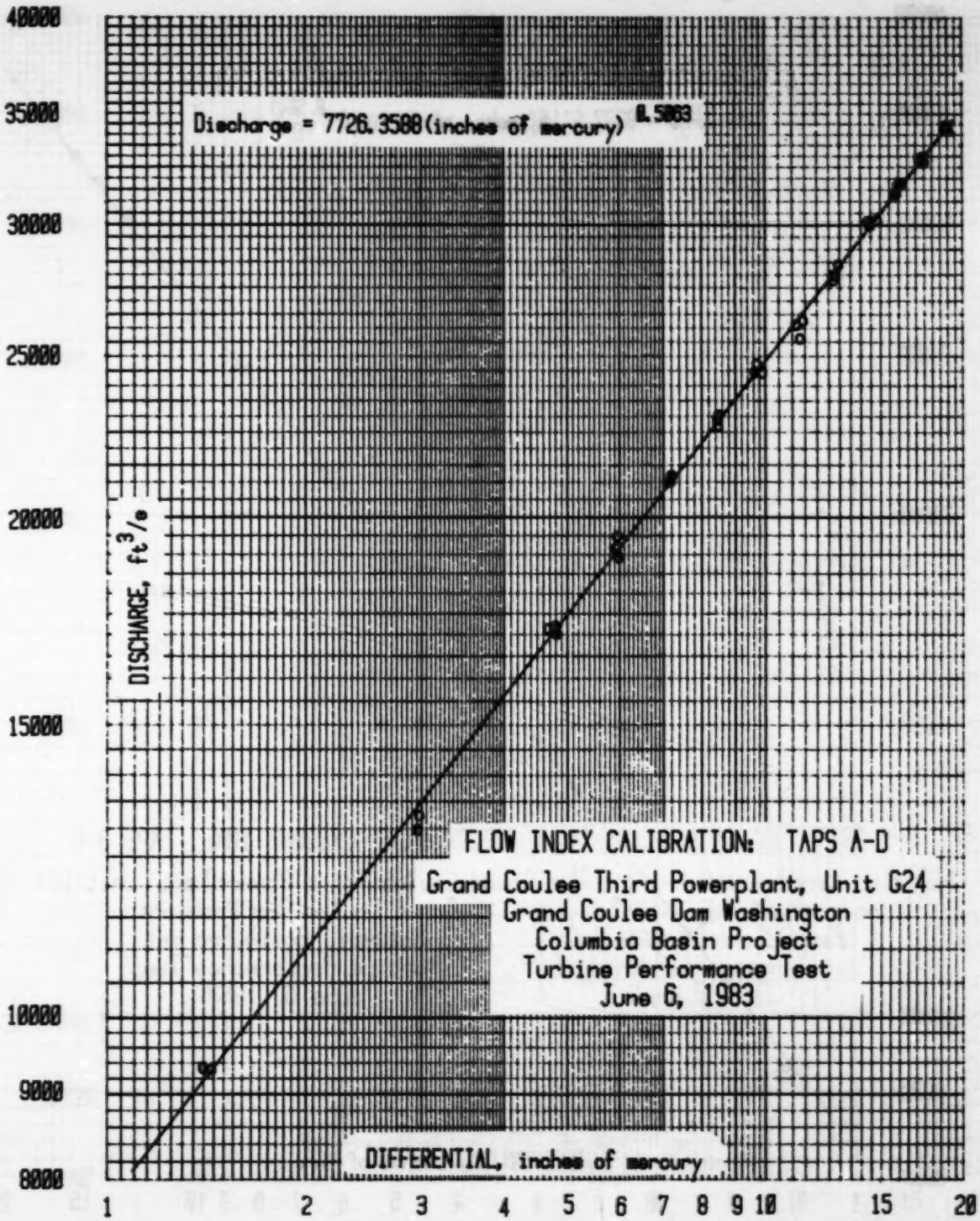


Figure 4. – Flow index calibration – taps A–D.

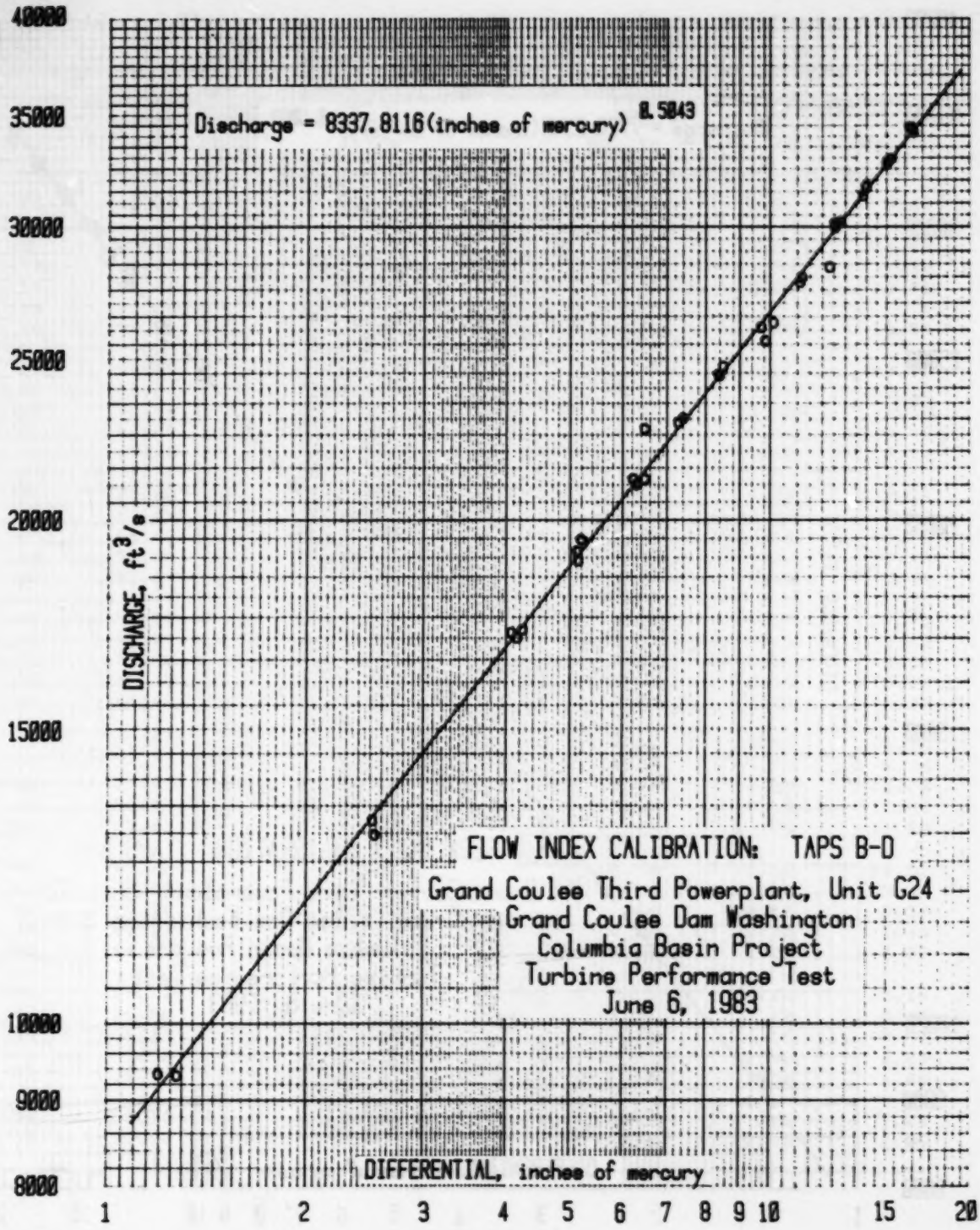


Figure 5. – Flow index calibration – taps B–D.

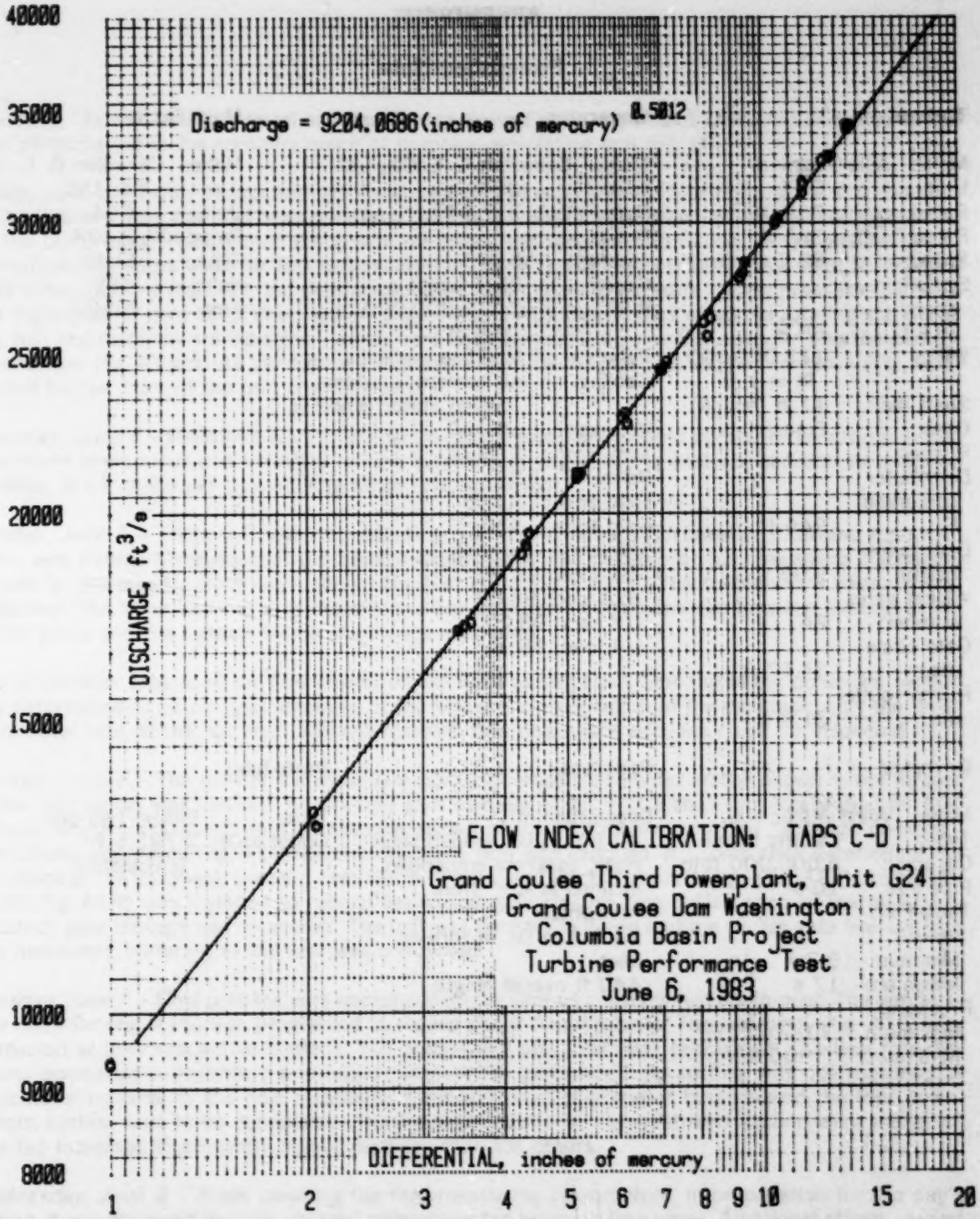


Figure 6. – Flow index calibration – taps C–D.

APPENDIX 1

Powerplant Data

Turbine

Make:	Allis-Chalmers
Unit:	G24
Rated hp:	960,000
Rated head:	285 ft
Speed:	85.7 r/min
Specific speed (B.E.)	65.8
WR^2:	178,000,000 lb at 1 ft
Shaft dia.:	11 ft (hollow)
Case:	Francis
Runner:	
Distributor centerline El.:	946 ft
Distributor height:	9.08 ft
Wicket gates number:	24
Gate circle dia.:	34.67 ft
Runner outlet dia.:	31.8 ft

Generator

Make:	Canadian G. E. Co., Ltd.
Unit:	G24
Rated kV·A:	717,949
Power factor:	0.975
Speed:	85.7 r/min
WR^2:	2,110,000,000 lb at 1 ft
Type:	Modified umbrella
Cooling:	Air coolers + water cooled stator windings
Voltage:	15,000
Arm. amp.:	27,635
Poles:	84
Field amp.:	3,795
Field volts:	330
Efficiency – percent	
Full load:	98.60
3/4 load:	98.62
l/2 load:	98.20
l/4 load:	96.94

Main Exciter

Make:	Canadian G. E. Co., Ltd.
Unit	G24
Rated kW:	2,434
Type:	Static
Volts:	468
Amp:	5,200

Governor

Make:	Voest Alpine A.G.
Type:	Electric hydraulic
Capacity:	6,000,000 ft-lb
Pipe size:	10 in
Time–Full Stoke:	
Minimum:	9.3 s
Maximum	17 s
Pressure:	
Maximum:	1,000 lbf/in²
Minimum:	900 lbf/in²

Penstock

Description:
40 ft 0 in i.d. welded steel plate, concrete embedded, inclined at 45° from horizontal
34 ft 8 in i.d. at turbine inlet
440 ft overall length

Draft tube

Type:	Elbow–Two pier
Outlet area:	2,793.6 ft² (calculated)

APPENDIX 2

Test Log

Thursday, June 2. – LeRoy Heigel and Jan Favero arrived at Grand Coulee Dam. Al Lewey was at the dam participating in the commissioning of pumping-generating unit PG/10.

Friday, June 3. – LeRoy Heigel and Jan Favero joined Al Lewey at the Third Powerplant and reviewed the preliminary work that had been completed for the test. Dennis Clinkenbeard, project representative for the performance test, joined the group. An inspection was made to review the installation of the mercury manometers used for flow tap calibration (fig. A1), the field mercury gage used to measure draft tube pressure (fig. A2), the deadweight gage tester used to measure casing pressure (fig. A3), and the computer data acquisition system (figs. A4 and A5). Electricians wired the rotating standards (fig. A6) and electrical transducers – which were used to measure generator output – into the current transformer (fig. A7 and A8) and potential transformer (fig. A9) circuits at the test block (fig. A10) located on the front of the unit control board.

Saturday, June 4. – Revisions were made to the data acquisition system computer programs. A displacement transducer was installed on one servomotor (fig. A11) to indicate servomotor position (stroke). Work continued on installing other test equipment.

Sunday, June 5. – Michael Byrne (representing the Allis-Chalmers Corporation), turbine manufacturer, and Dennis Kistenmacher (of Stanley Consultants, the Contractor for measuring discharge) arrived at the jobsite. Both were shown the test equipment setup. The turbine flow passage was inspected. The lower wearing ring clearances were measured. The clearances between the end of the wicket gates and the bottom facing plate were measured.

The piezometer taps used for flow measurement were backflushed. One tap in the upstream section was determined to be plugged. Because of the size and configuration of the penstock, only the lower piezometer taps at the net head and downstream flow measuring sections could be inspected.

Monday, June 6. – The relation between gate opening versus servometer stroke shown in the turbine model test report was verified. An average gate opening of 25.947 inches was established as 100 percent which corresponds to a servomotor stroke of 26.157 inches from the "squeeze position." The Gibson apparatus (fig. A12) used to measure flow was installed. A survey crew determined the elevations at the deadweight tester, field mercury gage, and electric contact gage (fig. A13). An oscillograph (fig. A14) was installed to record the wicket gate closure rate during each of the test runs. Penstock gate leakage was measured. The unit was partially watered and the wicket gate leakage rate was measured. Watering of the unit was completed.

Tuesday, June 7. – Final preparations were made on the various pieces of test equipment. The temperature recorder (fig. A15) was programed to record stator temperatures. The test party (fig. A16) was instructed at their respective stations. Ten preliminary test runs were performed. The flow rate diagrams appeared satisfactory and adjustment of the governor time setting was not required. A piezometer traverse of the flow measuring (pressure-time) piezometer taps showed the four downstream section taps to be acceptable. The traverse results for the upstream section were marginal. One tap indicated significantly higher readings than the others.

Wednesday, June 8. – While bleeding the flow-measuring piezometers, in preparation for the day's testing, it was observed that the plugged piezometer tap began to flow water. Additional efforts caused the blockage to dislodge and the tap was returned to service. Another piezometer traverse was performed; and this showed that the formerly plugged tap along with the diametrically opposite tap produced acceptable results. It allowed the first pair of taps, which previously had supplied marginal

results, to be shut off. The test was completed using the second tap arrangement. Testing continued through the day completing runs 11 through 30.

Thursday, June 9. – Runs 31 through 52 were made. Pending review of the results, the test was completed. Calibration of the flow-measuring apparatus was begun.

Friday, June 10. – Calibration of the flow-measuring apparatus was completed. Preliminary calculations were made for six of the test runs. The results correlated well with the performance predicted by the model test. All parties agreed the test was complete. The test instruments were disassembled and prepared for shipment.

Saturday, June 11. – The test party departed.

Figure A1. – Differential mercury manometers. Flow index calibration. Photo P801-D-80509

Figure A2. – Field mercury gage. Turbine outlet pressure. Photo P801-D-80510

Figure A3. – Deadweight gage tester. Turbine inlet pressure. Photo P801-D-80511

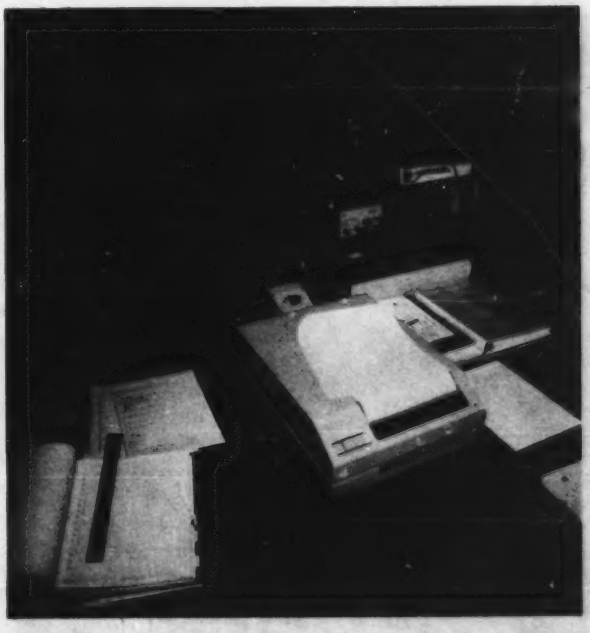


Figure A4. – Electrical transducers for power measurement and data acquisition system. Photo P801-D-80512

Figure A5. – HP-9825 Controller for data acquistion system. Photo P801-D-80513

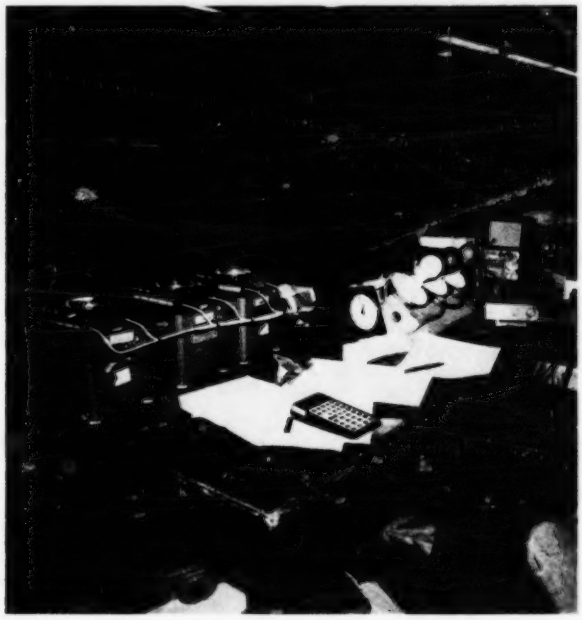


Figure A6. – Rotating standards for power measurement. Photo P801-D-80514

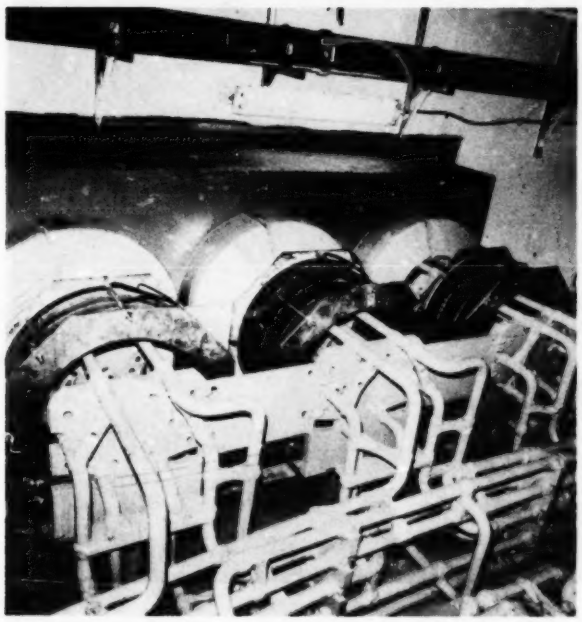


Figure A7. – Generator current transformers. Photo P801-D-80515

Figure A8. – Secondary leads from current transformer. Photo P801-D-80516

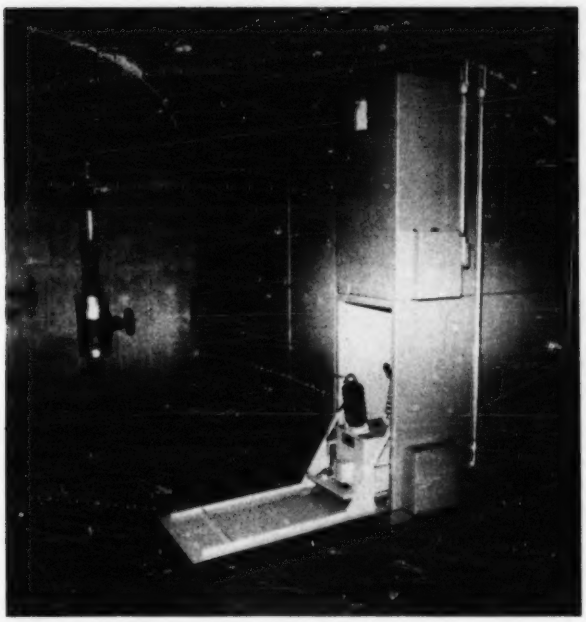


Figure A9. – Generator potential transformers. Photo P801-D-80517

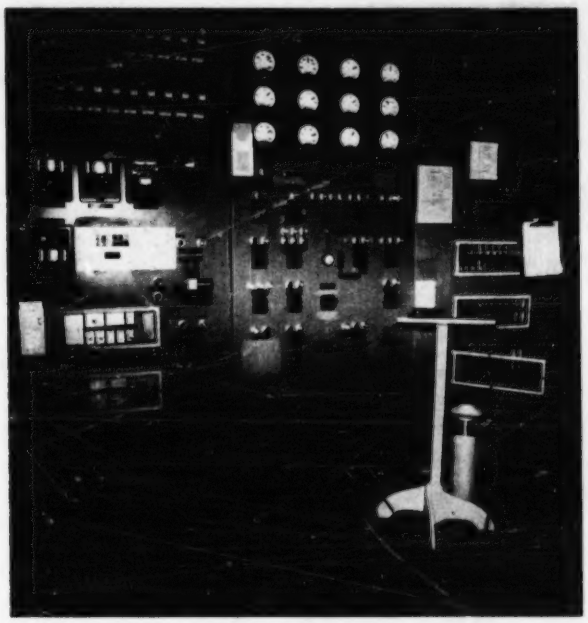


Figure A10. – Connection of electrical instruments to control board. Photo P801-D-80518

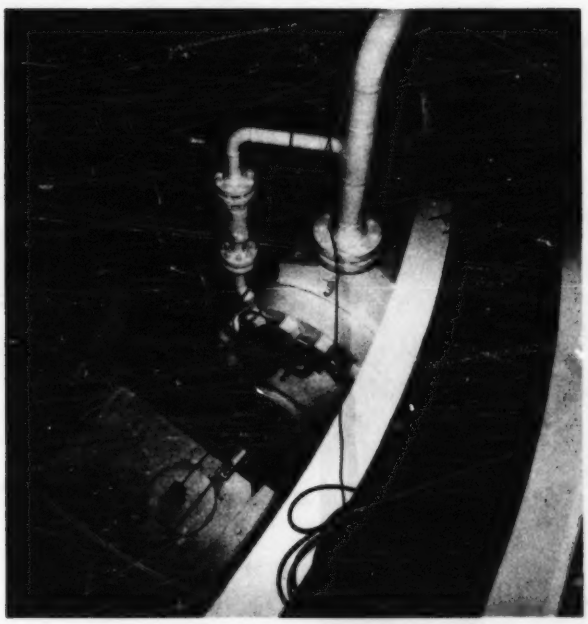


Figure A11. – Displacement transducer for measuring measuring wicket gate position. Photo P801-D-80519

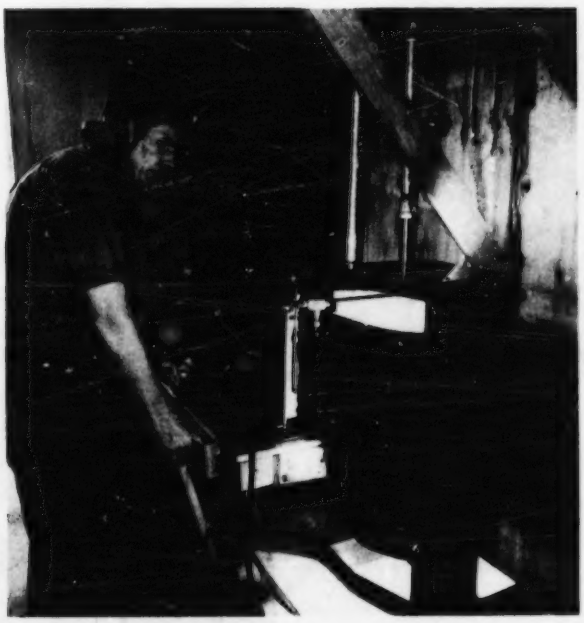


Figure A12. – Gibson apparatus for measuring rate of discharge. Photo P801-D-80520

Figure A13. – Electric contact gage for measuring forebay water surface elevation. Photo P801-D-80521

Figure A14. – Starters table and oscillograph. Photo P801-D-80522

Figure A15. – Temperature monitor. Photo P801-D-80523

Figure A16. – Grand Coulee turbine performance test party.

Top Row
B. Bischoff, J. Favero, D. Rey, L. Heigel, M. Thompson, A. Lewey, B. Wright, R. Whitehead, L. Brieler.

Bottom row
D. Kistenmacher, M. Byrne, L. Carlson, C. Lindor, G. Walstrom, R. Leith. June 1983. Photo P801-D-80524

APPENDIX 3

Spiral Case Piezometer Traverse

Readings were taken on the spiral case pressure gage (deadweight gage tester) for each piezometer separately, for diametrically opposite pairs, and for all four piezometers combined. Traverse readings were taken on the morning of June 9, 1983.

	Piezometers open						
	A	B	C	D	A&C	B&D	All*
Gage pressure, lb/in²	119.1	118.9	119.1	119.5	119.2	119.4	119.15
Pressure head, ft	275.4	275.0	275.4	276.3	275.7	276.1	275.5
Average of all four read separately, ft			275.5				
Variation from average, ft	–0.1	–0.5	–0.1	+ 0.8	+ 0.2	+ 0.6	0.0
Variation between pairs, ft			0.4				
Variation, % of h_v	–0.8	–3.9	–0.8	+ 6.3	+ 1.6	+ 4.7	0.0

The spiral case pressure gage (deadweight gage tester) conversion factor is 2.3125 ft/(lb/in²).

Approximate $Q = 27{,}000$ ft³/s $\quad A_j = 941.88$ ft² $\quad g_c = 32.1783$

$$H_{vi} = \frac{1}{A_j^2\, 2g_c} Q^2 = 17.515 \times 10^{-9}\, Q^2 = 12.769 \text{ ft}$$

* Average of two readings.

APPENDIX 4

Determination of Gravity

Plant latitude			47° 58'
Standard gravity g_o*			32.1741 ft/s²
Standard gravity corrected for latitude‡			32.1812 ft/s²
Local gravity g_1 at *zero* elevation of deadweight gage tester:			
Zero elevation at deadweight tester gage			971.17 ft
Altitude correction†		(–)	0.0030 ft/s²
$g_1 = 32.1812 - 0.0030$			32.1782 ft/s²
Local gravity g_2 at distributor centerline (spiral case extension piece):			
Elevation at distributor centerline			946.00 ft
Altitude correction †		(–)	0.0029 ft/s²
$g_2 = 32.1812 - 0.0029$			32.1783 ft/s²
Local gravity g_3 at outer end of draft tube:			
Elevation draft tube centerline			881.28 ft
Altitude correction †		(–)	0.0027 ft/s²
$g_3 = 32.1812 - 0.0027$			32.1785 ft/s²
Zero elevation at field mercury gage			907.13 ft
Altitude correction †		(–)	0.0028 ft/s²
$g_4 = 32.1812 - 0.0028$			32.1784 ft/s²

• PTC 18.1–1978, Pumping Mode of Pump/Turbines, table 1, p. 6., *American Society of Mechanical Engineers*, 345 East 47th Street, New York, NY 10017.

‡ _____, table 38 (p. 20).

† Altitude correction = -3.086×10^{-6} (ft²/s)/ft.

APPENDIX 5

Weight of Water and Conversion Factors

Data from static check

	Check No. 1 (before test)		Check No. 2 (after test)
Reservoir elevation, ft	1263.47		1264.39
El. at deadweight gage tester, ft	971.17		971.17
Static head H_s ft	292.30		293.22
(average static head)		292.76	
Deadweight gage tester	126.40		126.80
reading P, lb/in²		126.60	
Water temperature, °C	14.25		14.75

Basic data

Gravity at latitude and zero elevation of deadweight gage tester ..... 32.1782 ft/s²

Standard gravity, g_o ..... 32.1741 ft/s²

Weight of water (where gravity is 32.1782 ft/s²):

$$\gamma = \frac{144\ P}{H_s}\left(\frac{g_1}{g_o}\right) = \frac{144(126.60)}{292.76}\left(\frac{32.1782}{32.1741}\right) = 62.279\ \text{lb/ft}^3$$

Conversion factor

Ratio of feet of water to lb/in² = H_s/P = 292.76/126.60 = 2.3125 ft/(lb/in²)

Ratio of Feet of Water to Feet of Mercury

A field mercury gage was used to measure turbine outlet pressure. The measured values were recorded in feet of mercury and referenced to the gage *zero* elevation. The ratio factor calculations are:

Standard gravity g_o is 32.7141 ft²/s.

Local gravity at *zero* elevation of field mercury gage g_4 was determined as 32.1784 ft²/s.

Ambient air temperature is 21.8 °C.

Relative density of mercury at 21.8 °C and standard gravity is 13 541.8 kg/m³.

$$(13\,541.8\ \text{kg/m}^3)\ 1.0\ \text{lb/ft}^3/16.01846\ \text{kg/m}^3 = 845.39\ \text{lb/ft}^3$$

At gage *zero* elevation, the weight of mercury is

$$845.39\ (32.1784/32.1741) = 845.50\ \text{lb/ft}^3$$

$$\frac{845.50\ \text{lb/ft}^3}{\text{ft-mercury}}\ \frac{62.279\ \text{lb/ft}^3}{\text{ft-water}} = 13.576\ \frac{\text{ft-water}}{\text{ft-mercury}}$$

APPENDIX 6

Wicket Gate Leakage Test

Plant: Grand Coulee Third Powerplant, Unit G24 — Date: June 6, 1983

Penstock inside diameter: 40 ft — Penstock area: 1,256.64 ft²

Upper water surface elevation: 1262.04 — Water temperature: 14.25 °C

Casing pressure gage *zero* El.: 971.17 ft — Gage type: Deadweight tester

Draft-tube pressure gage *zero* El.: 907.13 ft — Gage type: Field mercury gage

Reading No.	Time		Spiral case pressure		Draft tube	
	minute:seconds	seconds	lb/in²	ft	Pressure ft-Hg	Pressure El. ft
1	0	0	47.5	1,081.01	4.06	962.25
2	15:34	934	45.0	1,075.23	4.06	962.25
3	32:08	1,928	42.5	1,069.45	4.06	962.25
4	49:31	2,971	40.0	1,063.67	4.06	962.25

Spiral case pressure El., ft= spiral case pressure, lb/in² (2.3125) + 971.17

Draft tube pressure El., ft= draft tube pressure, ft-Hg (13.576) + 907.13

2.3125 [ft/(lb/in²)] = (spiral case pressure) (deadweight gage tester conversion factor)

971.17 ft= spiral case pressure gage *zero* elevation

13.576 = relative density of mercury to water

907.13 ft= draft tube pressure gage *zero* elevation

APPENDIX 6 – Continued

Spiral case pressure elevation H_1, (ft)	Spiral case pressure elevation H_2, (ft)	Volume V, (ft^3)	Time T_1, (s)	Time T_2, (s)	Wicket gate leakage q_1, (ft^3/s)	Head gate leakage q_2, (ft^3/s)
1081.01	1075.23	10,272	0	934	11.00	0
1075.23	1069.45	10,272	934	1928	10.33	0
1069.45	1063.67	10,272	1928	2,971	9.85	0

$$\text{Volume } V = \frac{A}{\sin\theta}\,(H_1 - H_2),\ ft^3$$

A = area of penstock = 1,256.64 ft^2
θ = slope of penstock = 45°
$q_1 = V/(T_2 - T_1)$
q_2 = 0: q_2 was determined negligible immediately prior to the test

Spiral case pressure elevation ft	Draft-tube pressure elevation ft	Net effective head H_e	K_g
1081.01	962.25	118.76	1.022
1075.23	962.25	112.98	0.985
1069.45	962.25	107.20	0.964
1063.67	962.25	101.40	

H_e = net effective head across the turbine wicket gates = spiral case pressure elevation – draft tube pressure elevation

The wicket gate leakage coefficient K_g is determined from the equation:

$$q_o = K_g h^{1/2} \quad \text{or} \quad K_g = \frac{q_o}{h^{1/2}}$$

where

$$q_o = q_1 - q_2$$

and

$$h = \frac{H_{e_1} + H_{e_2}}{2}$$

Average K_g = 0.990

Wicket gate leakage = 0.990 H_e

APPENDIX 6 – Continued

Wicket Gate Leakage Sample Computation – Run No. 15

Static Head

Spiral case gage *zero* elevation	971.17 ft
Distributor centerline elevation	(–) 946.00 ft
	25.17 ft
Spiral case static pressure (lb/in²) 2.3125	(+) 292.53 ft
Static head H_s	= 317.70 ft

Pumping Head

Pumping head gage *zero* elevation	974.31 ft
Distributor centerline elevation	(–) 946.00 ft
	28.31 ft
Pumping head gage pressure (lb/in²) 2.3125	(+) 53.19 ft
Pumping head H_p	= 81.50 ft

Effective Head

$H_e = H_s - H_p$ = 236.2 ft

Wicket Gage Leakage

$q = k_g H_e^{1/2}$ = 15.2 ft³/s

2.3125 ft/(lb/in²) = spiral case (deadweight gage tester) weight of water conversion factor (see app. 5)

K_g = 0.990 (see app. 6)

APPENDIX 7

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

GRAND COULEE POWER PLANT

Unit No. G24 June 8-9, 1983

PIPE FACTOR

Station	Penstock Diameter (feet) Vertical	Horizontal	45°	135°	Average	A Penstock Area (sq.ft.)	a Average Area (sq.ft.)	L Incremental Length (feet)	L/a
1	39.96	40.03	39.97	39.98	39.985	1255.69			
							1256.64	10.00	0.007958
2	40.00	40.03	---	---	40.015	1257.58			
							1258.05	10.00	0.007949
3	40.02	40.04	---	---	40.030	1258.52			
							1257.27	10.00	0.007954
4	40.01	39.97	---	---	39.990	1256.01			
							1255.38	10.00	0.007966
5	39.98	39.96	---	---	39.970	1254.75			
							1256.17	10.00	0.007961
6	40.00	40.03	---	---	40.015	1257.58			
							1256.95	10.00	0.007956
7	40.01	39.98	---	---	39.995	1256.32			
							1256.01	10.00	0.007962
8	39.97	40.00	---	---	39.985	1255.69			
							1256.79	10.06	0.008005
9	40.04	40.02	40.00	40.02	40.020	1257.89			
								ΣL = 80.06 feet	
								F = ΣL/a = 0.063711	

$A = \pi/4 \times (\text{Average Diameter})^2$

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

GRAND COULEE POWER PLANT

Unit No. G24 June 8-9, 1983

CALIBRATION FACTORS FOR GIBSON APPARATUS

Official Run No.	Temperature of Mercury °C	Density of Mercury	M Relative Density	R Ratio of Areas	K Calibration Factor
15	29.7	13.5225	13.5282	0.1720	39.373
16	29.8	13.5222	13.5279	0.1709	39.335
17	30.2	13.5212	13.5269	0.1712	39.342
18	31.0	13.5193	13.5250	0.1722	39.369
20	30.8	13.5198	13.5255	0.1715	39.347
21	31.0	13.5193	13.5250	0.1722	39.369
22	30.9	13.5195	13.5252	0.1715	39.346
23	30.0	13.5217	13.5274	0.1720	39.370
24	29.0	13.5242	13.5299	0.1709	39.341
25	28.4	13.5256	13.5313	0.1718	39.376
26	28.0	13.5266	13.5323	0.1718	39.379
27	28.0	13.5266	13.5323	0.1714	39.365
28	27.9	13.5268	13.5325	0.1720	39.386
29	27.7	13.5274	13.5331	0.1715	39.371
30	27.2	13.5286	13.5343	0.1722	39.398
31	20.3	13.5455	13.5512	0.1720	39.445
32	20.6	13.5448	13.5505	0.1715	39.426
33	20.8	13.5443	13.5500	0.1718	39.434
34	21.3	13.5431	13.5488	0.1710	39.404
35	21.3	13.5431	13.5488	0.1714	39.417
36	21.8	13.5418	13.5475	0.1714	39.413
37	22.3	13.5406	13.5463	0.1714	39.409
38	23.0	13.5389	13.5446	0.1710	39.390
39	23.3	13.5382	13.5439	0.1713	39.398
40	23.8	13.5369	13.5426	0.1715	39.401
41	24.0	13.5364	13.5421	0.1720	39.416
42	24.2	13.5359	13.5416	0.1718	39.408
43	24.5	13.5352	13.5409	0.1715	39.396
44	25.0	13.5340	13.5397	0.1712	39.382
45	26.0	13.5315	13.5372	0.1710	39.367

CALIBRATION FACTORS FOR GIBSON APPARATUS (continued)

Official Run No.	Temperature of Mercury °C	Density of Mercury	M Relative Density	R Ratio of Areas	K Calibration Factor
46	26.0	13.5315	13.5372	0.1720	39.401
47	26.2	13.5310	13.5367	0.1722	39.406
48	26.1	13.5313	13.5370	0.1722	39.407
49	26.8	13.5296	13.5353	0.1714	39.375
50	26.3	13.5308	13.5365	0.1722	39.405
51	26.8	13.5296	13.5353	0.1723	39.405
52	27.0	13.5291	13.5348	0.1718	39.387

Relative Density of Water = 0.99927 (at 14.0°C water temperature and atmospheric pressure)

Effect of pressure at 108 psi gage pressure on manometer = 0.99969

M = Relative Density of Mercury = (Density of Mercury ÷ 0.99927)(0.99969) (at atmospheric pressure)

R = Ratio of areas, glass tube to steel riser for Apparatus No. 19, Glass Tube No. 19-4 and 3/4" Steel Riser (varies with range of deflections on diagrams)

$K = \frac{g}{12}(R+1)(M-1)$; where g = 32.178 at latitude N47°58' and elevation 1015 feet

APPENDIX 7 - Continued

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

GRAND COULEE POWER PLANT

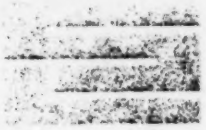
Unit No. G24 June 8-9, 1983

TURBINE DISCHARGE

Run No.	Turbine Discharge (cfs)	Run No.	Turbine Discharge (cfs)
15	28,352	46	20,992
16	30,178	47	19,139
17	31,297	48	16,988
18	32,822	49	13,210
20	34,195	50	9,311
21	34,394	51	9,289
22	32,706	52	12,952
23	31,710		
24	29,945		
25	27,765		
26	25,591		
27	24,404		
28	22,993		
29	21,150		
30	19,453		
31	17,172		
32	17,112		
33	18,897		
34	21,150		
35	22,665		
36	24,420		
37	26,077		
38	34,372		
39	32,920		
40	31,648		
41	30,115		
42	27,951		
43	26,241		
44	24,699		
45	22,855		

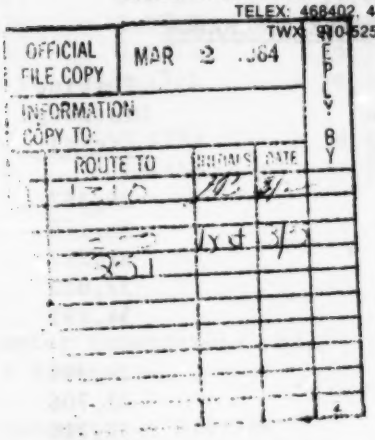
These values are at test head conditions.
These values do not include wicket gate leakage.

APPENDIX 8



STANLEY CONSULTANTS, INC.

STANLEY BUILDING, MUSCATINE, IOWA 52761
TELEPHONE: 319/264-6600
CABLE: STANLEY MUSCATINE IOWA
TELEX: 468402, 468403
TWX: 910-525-1430



February 27, 1984

Assistant Commissioner - Engineering & Research
Bureau of Reclamation
Building 67, P. O. Box 25007
Denver Federal Center
Denver, Colorado 80225

Code D-250

Gentlemen:

Re: Turbine Performance Test
Grand Coulee, Unit G24
Contract No. 3-CS-10-05740

We have reviewed the preliminary copy of your report on the subject test at Grand Coulee Power Plant. This letter is to serve as our witness statement, in accordance with Paragraph F.1.c. of our agreement.

In our opinion, the methods and principles used in determining the hydraulic quantities embodied in this report comply with the requirements of Power Test Code PTC-18, approved by the American Society of Mechanical Engineers in 1949, except for the modifications noted in the report. The values of discharge from Gibson diagrams, Calibration of Gibson Apparatus and Pipe Factor are as furnished by us under the dates of July 29, and August 9, 1983. Our comments do not pertain to the determination of turbine output which is not included within the scope of our work.

Based upon estimated possible index errors in penstock measurements, repeatability of Gibson Apparatus calibration and variation between computed discharges obtained at the same gate opening, we estimate that the probable errors of individual discharge measurements are within 0.75 percent and that the probable error of the average of three measurements at the same discharge is within 0.5 percent.

It is recognized that other inaccuracies in the water quantity measurement may exist, principally related to positioning the recovery line on the diagrams. In our opinion, such error for this test is of a small magnitude not significant to the results.

From **STANLEY CONSULTANTS, INC.** To Assistant Commissioner Date 2/27/84

Two piezometer lines from the upstream Gibson section were shut off during the test runs due to conditions found to exist during pretest inspections, and also due to piezometer traverse results. All four taps were connected at the downstream Gibson piezometer section. One opposite pair of taps was connected at the upstream section. The pair utilized was that designated by the tap numbers 2 and 4 on Figure 9 in the document Instructions for Hydraulic Turbine Performance Test at Grand Coulee Third Powerplant, Grand Coulee Unit G24, Columbia Basin Project.

We trust the statements above will meet your requirements.

Sincerely,

STANLEY CONSULTANTS, INC.

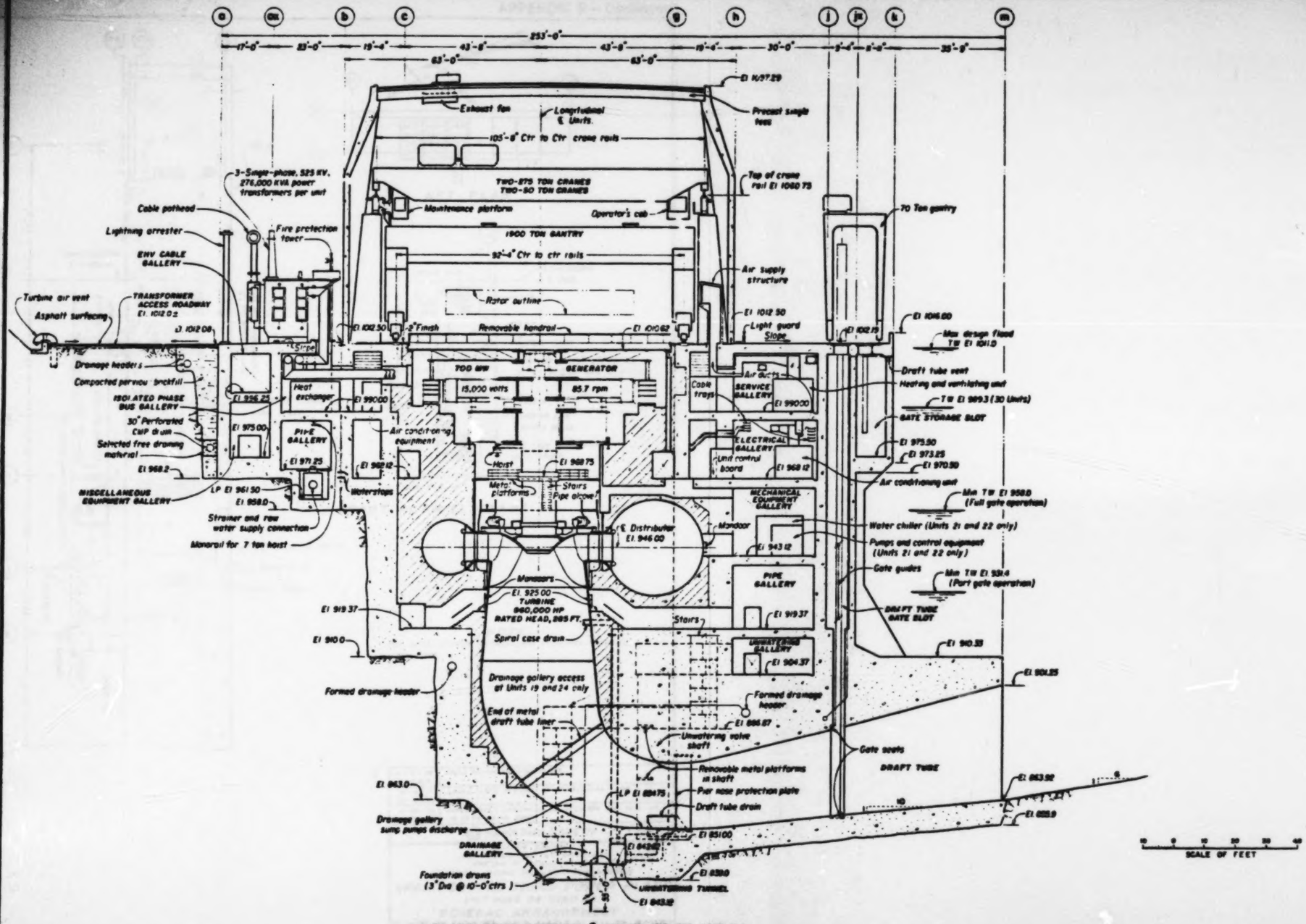
D. L. Foderberg

Dennis L. Foderberg, P.E.
Project Manager

DLK:jlt:8429

APPENDIX 9

ENGINEERING DRAWINGS



TRANSVERSE SECTION ℄ UNITS 22, 23, AND 24

NOTE

For notes, concrete symbols, and reference drawings, see (320).

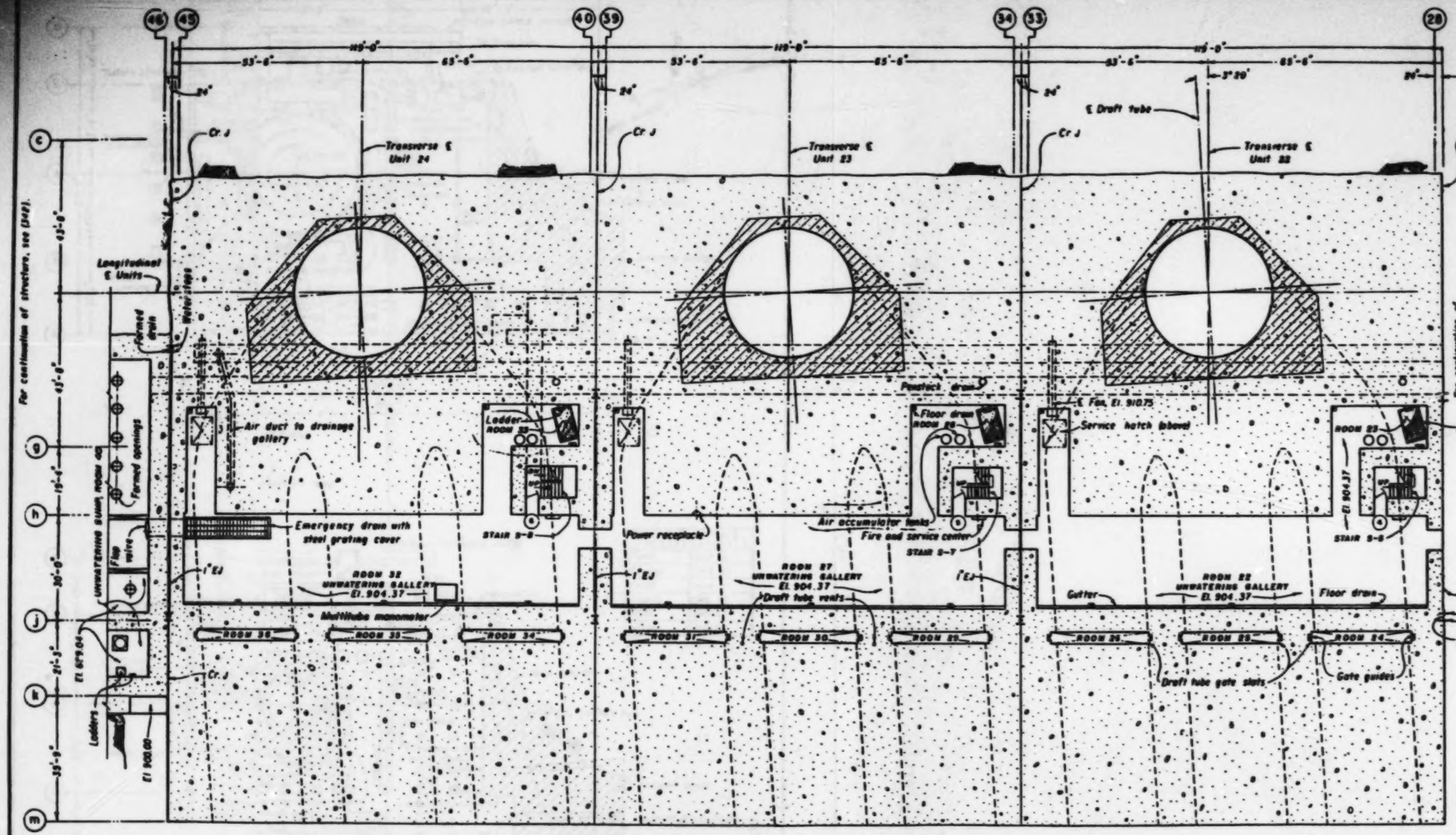
6-9-70	REVISED TRANSFORMERS IN UNITS 22, 23, AND 24.
8-8-68	

GUIDE SPEC: **SAFETY**

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

GRAND COULEE THIRD POWER PLANT
UNIT BAYS 22, 23, AND 24
GENERAL ARRANGEMENT
TRANSVERSE SECTIONS

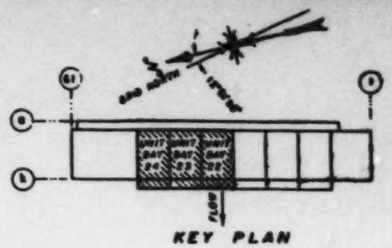
DENVER, COLORADO, SEPTEMBER 10, 1968



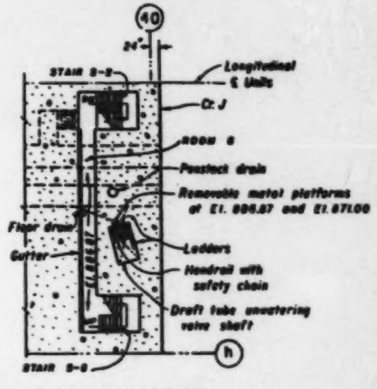
FLOOR - EL. 904.37

SCALE OF FEET

NOTE: TEMPORARY CHANGES MADE TO THIS DRAWING TO SHOW TEST EQUIPMENT



KEY PLAN



PART PLAN-EL. 886.87

NOTE

For notes, concrete symbols, and reference drawings, see (320).

9-8-70 9-E.O.R.	ADDED AIR ACCUMULATOR TANKS.
8-9-71 9-E.O.R.	ADDED SLOTS IN FLOOR OF UNWATERING SUMP.
8-20-70 9-E.O.R.	ADDED POWER RECEPTACLES, OPENINGS AND CURB AT 10 UNWATERING SUMP.

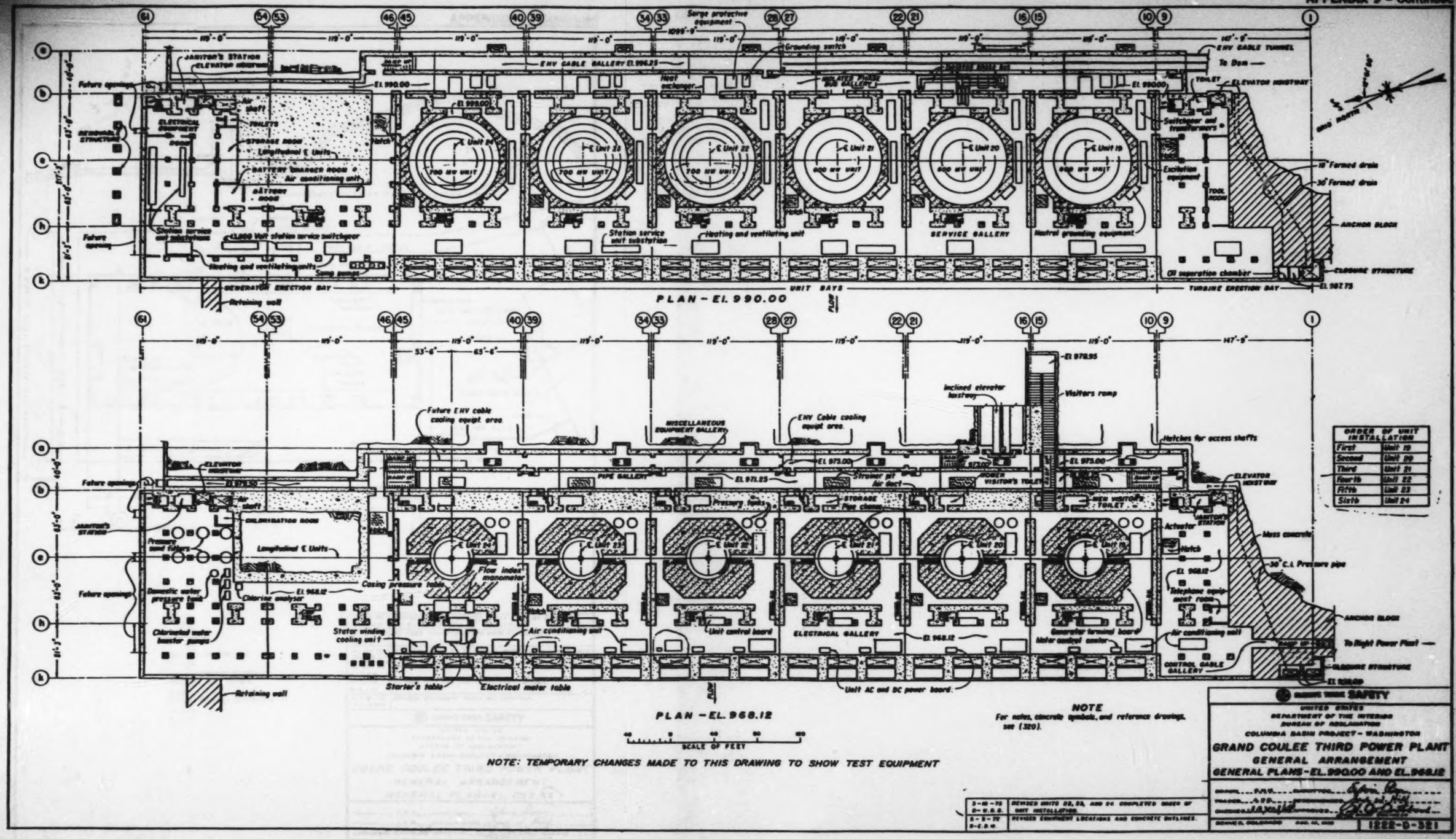
GIVING THEIR SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON

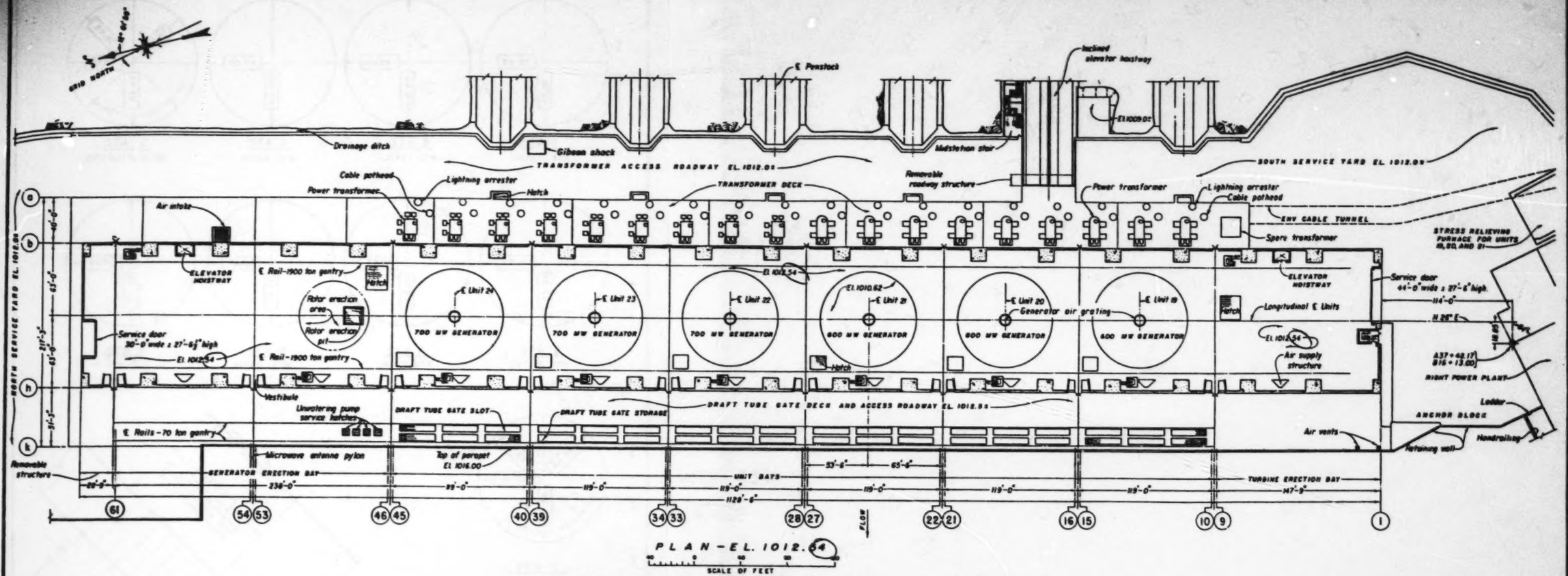
GRAND COULEE THIRD POWER PLANT
UNIT BAYS 22 THRU 24
GENERAL ARRANGEMENT
FLOOR-EL.904.37 AND PART PLAN-EL.886.87

DESIGNED ... A.P.R. ... SUBMITTED ...
TRACED ... A.P.P. ... RECOMMENDED ...
CHECKED ... APPROVED ...
DENVER, COLORADO, AUG 14, 1969

1222-D-341


PLAN – EL. 990.00
PLAN – EL. 968.12
SCALE OF FEET
NOTE
For notes, concrete symbols, and reference drawings, see (320).
NOTE: TEMPORARY CHANGES MADE TO THIS DRAWING TO SHOW TEST EQUIPMENT
ORDER OF UNIT INSTALLATION
First Unit 19
Second Unit 20
Third Unit 21
Fourth Unit 22
Fifth Unit 23
Sixth Unit 24
GENERATOR ERECTION BAY
UNIT BAYS
TURBINE ERECTION BAY
SERVICE GALLERY
ELECTRICAL GALLERY
CONTROL CABLE GALLERY
PIPE GALLERY
MISCELLANEOUS EQUIPMENT GALLERY
ENV CABLE GALLERY EL. 996.25
ENV CABLE TUNNEL
To Dam
To Right Power Plant
Visitors ramp
Inclined elevator hastway
Switchgear and transformers
Excitation equipment
Heating and ventilating unit
Station service unit substation
Neutral grounding equipment
Generator terminal board
Unit control board
Unit AC and DC power board
Air conditioning unit
Chlorination room
Longitudinal C Units
Battery charger room
Battery room
Toilets
Storage room
Janitor's station
Elevator hoistway
Hatches for access shafts
Anchor block
Mass concrete
30" C.I. Pressure pipe
Closure structure
Retaining wall
Oil separation chamber
Tool room
Control cable gallery
Telephone equipment room
Actuator
Hatch
Future openings
Future ENV cable cooling equipt area
ENV Cable cooling equipt area
Unit 19
Unit 20
Unit 21
Unit 22
Unit 23
Unit 24
700 MV UNIT
600 MV UNIT
EL. 990.00
EL. 973.00
EL. 968.12
EL. 978.95
EL. 971.25
EL. 962.75
1222-D-321

55



PLAN – EL. 1012.54

SCALE OF FEET

NOTE: TEMPORARY CHANGES MADE TO THIS DRAWING TO SHOW TEST EQUIPMENT

CONCRETE SYMBOLS

- First stage concrete
- Second stage concrete
- Mass concrete or concrete in adjacent structures
- Grouting mortar or blockout concrete

REFERENCE DRAWINGS

GENERAL ARRANGEMENT DRAWINGS	1222-D-320 THRU 349
STRUCTURAL ARRANGEMENT DRAWINGS:	
UNIT BAYS	1222-D-353 THRU 363
TRANSFORMER STRUCTURE	1222-D-364
VISITOR FACILITIES-LOWER STATION	1222-D-365
TURBINE ERECTION BAY	1222-D-366 THRU 370
GENERATOR ERECTION BAY	1222-D-371 THRU 380
SUPERSTRUCTURE	1222-D-381 THRU 388
VISITOR FACILITIES-MIDSTATION	1222-D-395 THRU 397
ARCHITECTURAL	1222-D-1389 THRU 1446
EXPANSION JOINT DETAILS	1222-D-412 THRU 415
BUILDING DETAILS	1222-D-416
FOUNDATION UPLIFT PRESSURE AND DRAINAGE PIPES	1222-D-392
TYPICAL REINFORCEMENT	1222-D-389, 404 THRU 407 AND 410
ANCHOR BLOCK RETAINING WALL	1222-D-418

NOTES

General arrangement drawings 1222-D-320 thru 349 show the ultimate construction and equipment.

For initial construction, see the structural arrangement drawings.

For stairs, doors, and finish schedules, see the architectural drawings.

⊖ Indicates door number 506. See door schedule drawings 1222-D-1394 and 1395.

10-22-62 D-W.J.C.	REVISED EL. OF FINISHED FLOOR FROM EL. 1012.0± TO EL. 1012.54 FOR 21 TRANSFORMERS.
6-8-73 D-W.S.S.	REVISED TRANSFORMERS IN UNITS 22, 23, AND 24.
3-10-73 D-W.S.S.	REVISED UNITS 22, 23 AND 24. ADDED SPARE TRANSFORMER.
3-15-73 D-E.B.W.	REVISED LIGHTNING ARRESTER LOCATION.
3-13-73 D-E.B.W.	REVISED NOTE FOR STRESS RELIEVING FURNACE.
5-8-73 5-E.B.W.	REVISED EQUIPMENT SIZES AND LOCATIONS.

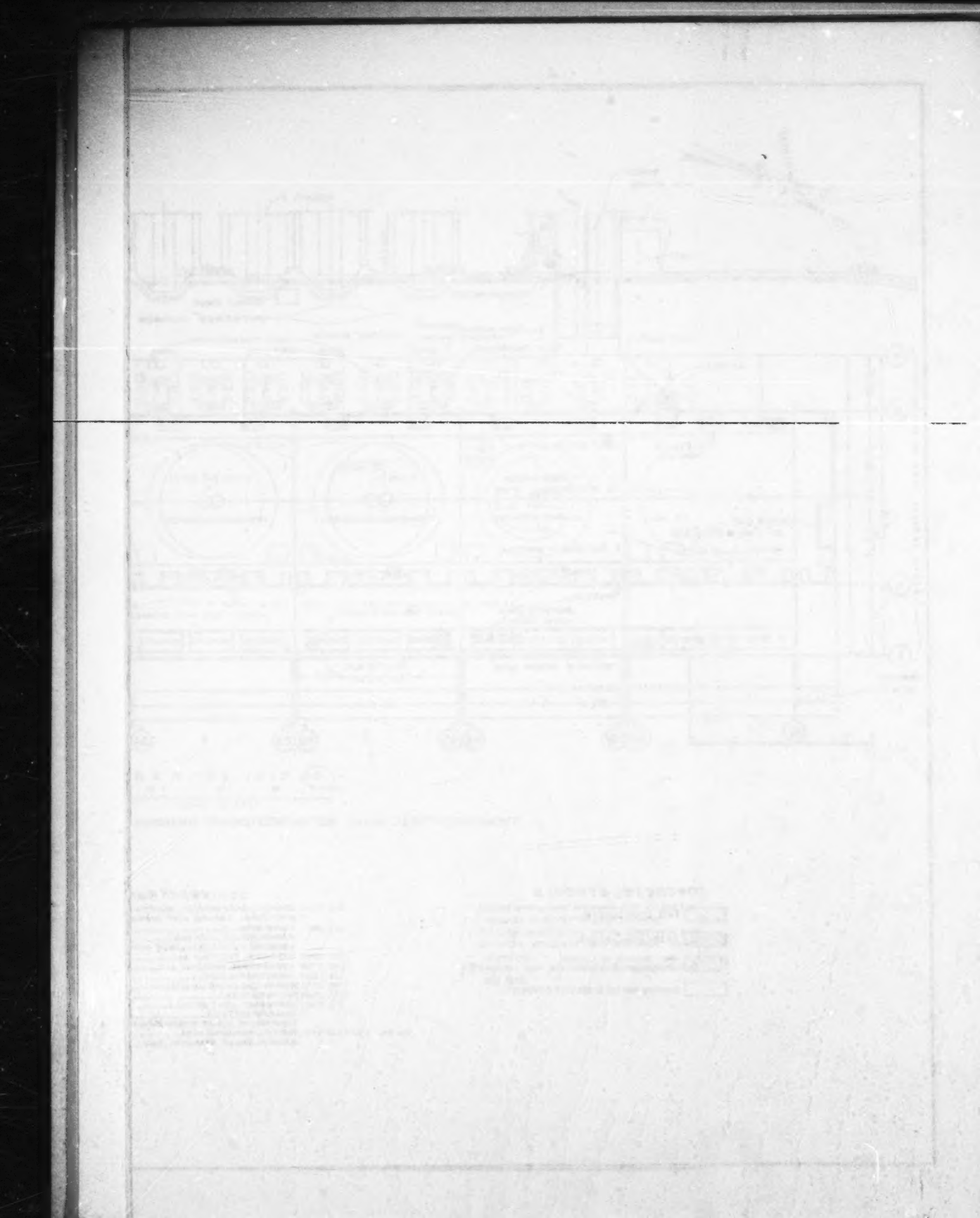
BUREAU THINK SAFETY

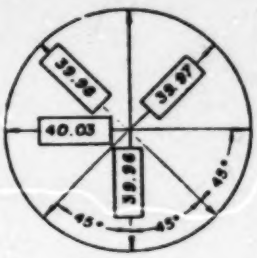
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT – WASHINGTON

GRAND COULEE THIRD POWER PLANT
GENERAL ARRANGEMENT
GENERAL PLAN-EL 1012.54

DRAWN A.P.P. — Chief, Design Br.
TRACED L.L.C. — Asst. Chief Engr.
CHECKED [illegible] — Chief Engr.
DENVER, COLORADO, AUG. 10, 1960

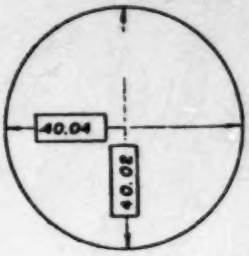
1222-D-320





STA. 1
PIEZOMETER SEC

STA. 2
INTER STA



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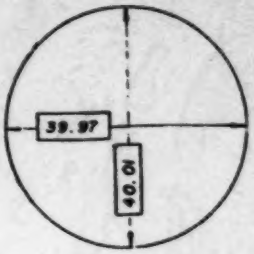
INTER STA



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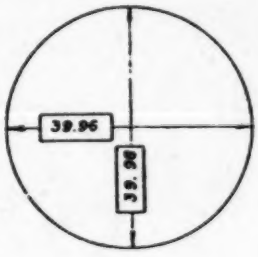
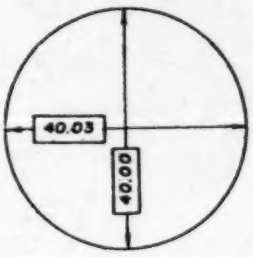
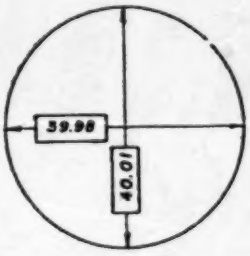
INTER STA



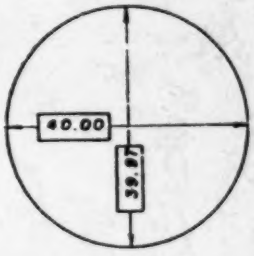
STA. 5
INTER SEC



STA. 6
INTER STA



STA. 7
INTER STA



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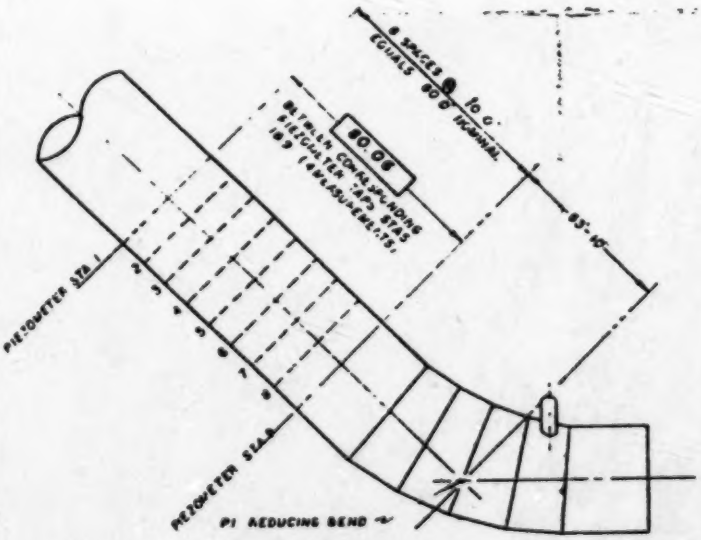
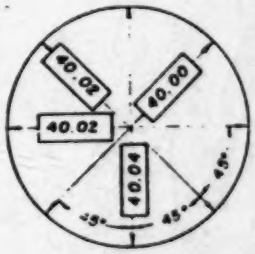
INTER STA





STA. 9
PIEZOMETER STA

NET HEAD PIEZOMETER TAP
TO BE MEASURED AT TIME OF TEST

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT – WASHINGTON

GRAND COULEE THIRD POWERPLANT

PENSTOCK 24

WATER PASSAGE CALIBRATIONS

DESIGNED _____ SUBMITTED _____
DRAWN RSH RECOMMENDED _____
CHECKED _____ APPROVED _____
GRAND COULEE, WASHINGTON AUG 6, 1973 SHEET 6 OF 8 | 1222-142-6143

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